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Issue 110

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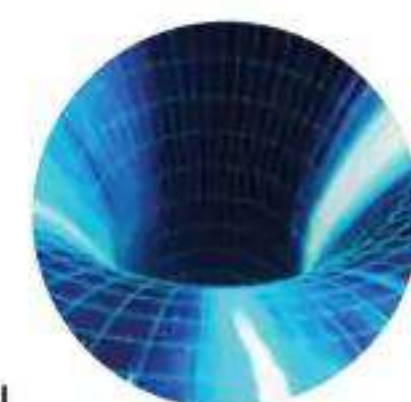
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Some of the biggest objects in the universe are also the most mysterious **36**



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These portals through space and time might be real after all, but how would we go about detecting one? **44**



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It's a groundbreaking finding that suggests there could be life elsewhere in the Solar System: the discovery of phosphine on Venus. One of the most hostile worlds in our solar neighbourhood isn't the first place that springs to mind in our search. But what's so important about phosphine, and why has it made us so excited?

Colourless, flammable and incredibly toxic, phosphine was found in the clouds of the Venusian atmosphere. It's in a place where it shouldn't be, and while it could be explained by processes so far unheard of, the research team, led by Jane Greaves at Cardiff University, suspect that it could relate to life. "I thought, well, just before we throw this away, I'll have a final go at [analysing the data]," Greaves said. "There was this line and it just wouldn't go away, and it seemed like it wasn't imaginary anymore. I was just completely stunned." Turn to page 14 for our full report.

Also this issue, we investigate whether the origin of the Wow! signal - a radio signal that was picked up in 1977 by Ohio State University's Big Ear radio telescope - has finally been pinpointed, meet the biggest galaxies in the universe and chat to *The Right Stuff's* technical consultant Robert Yowell about how far we'd be in landing humankind on the Moon without the advent of Project Mercury. Enjoy the issue!

GEMMA LAVENDER

EDITOR-IN-CHIEF

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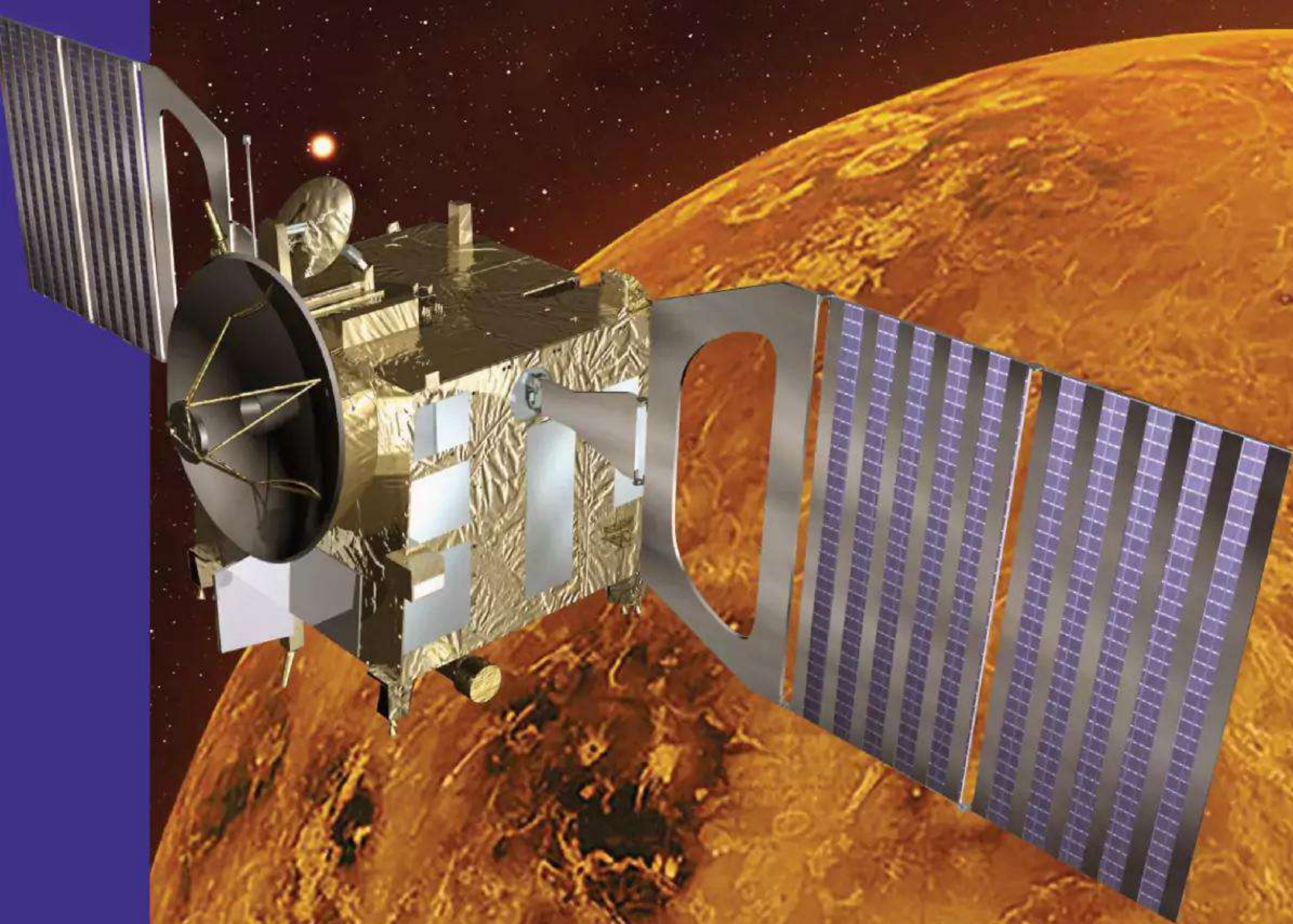


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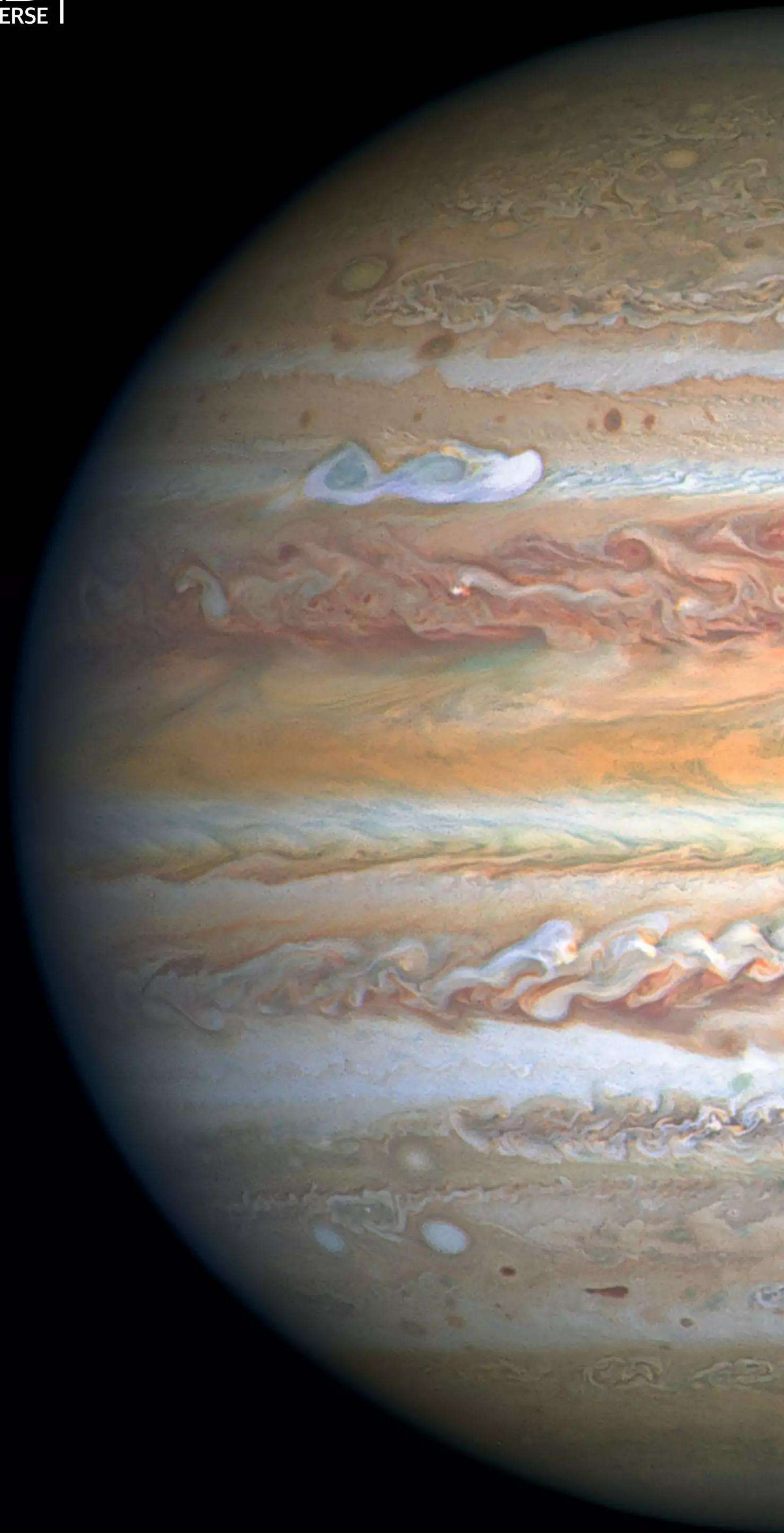
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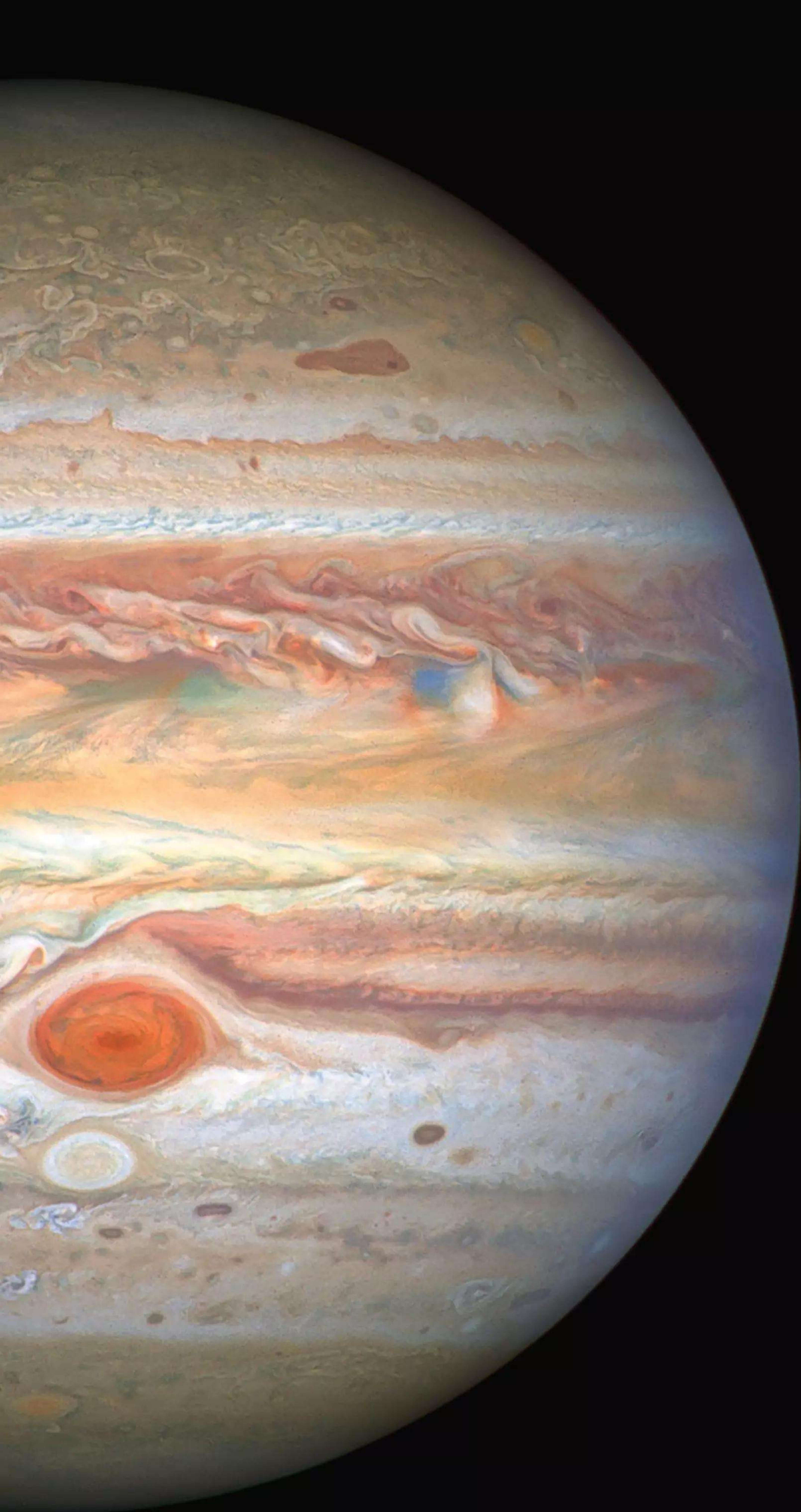
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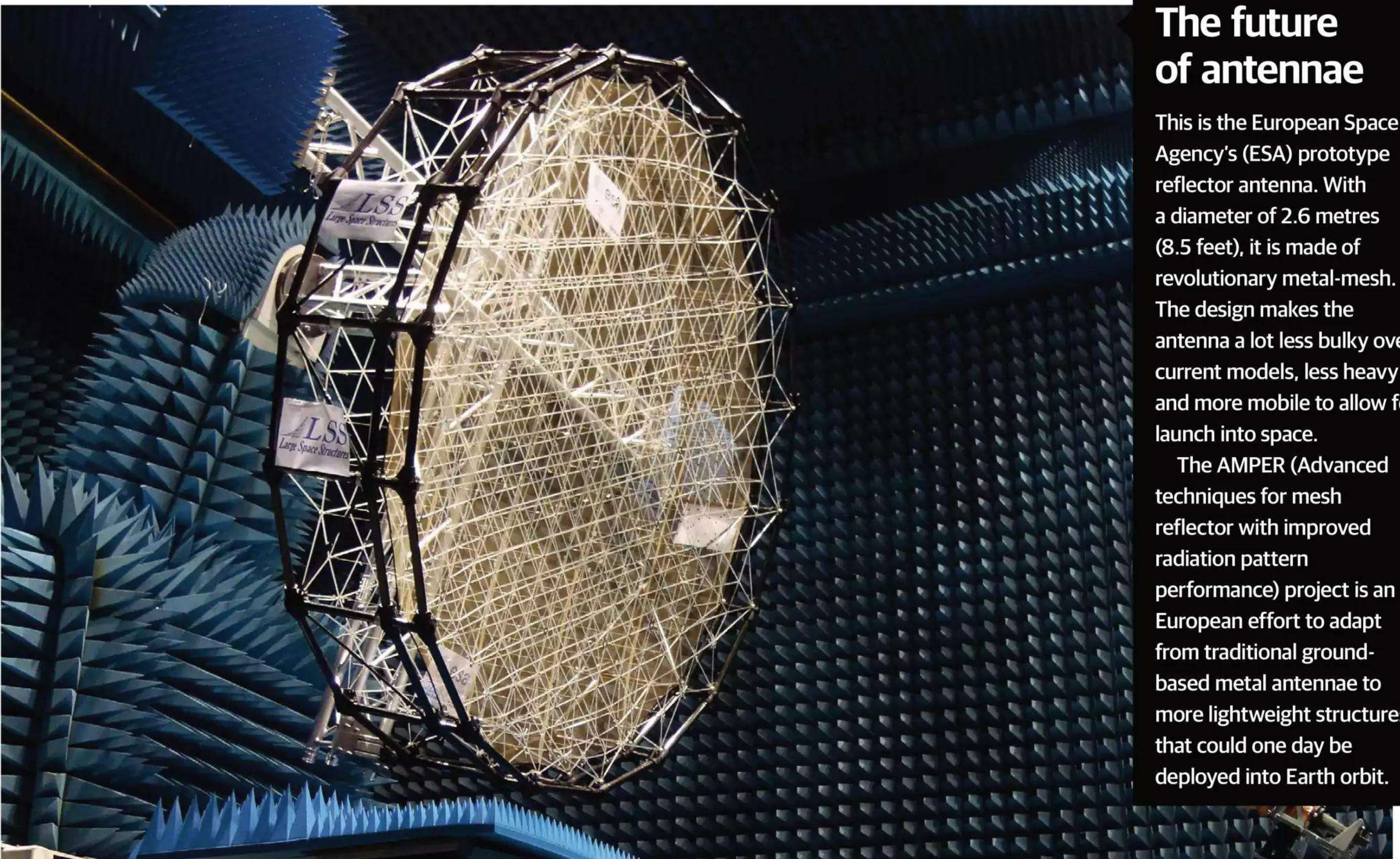
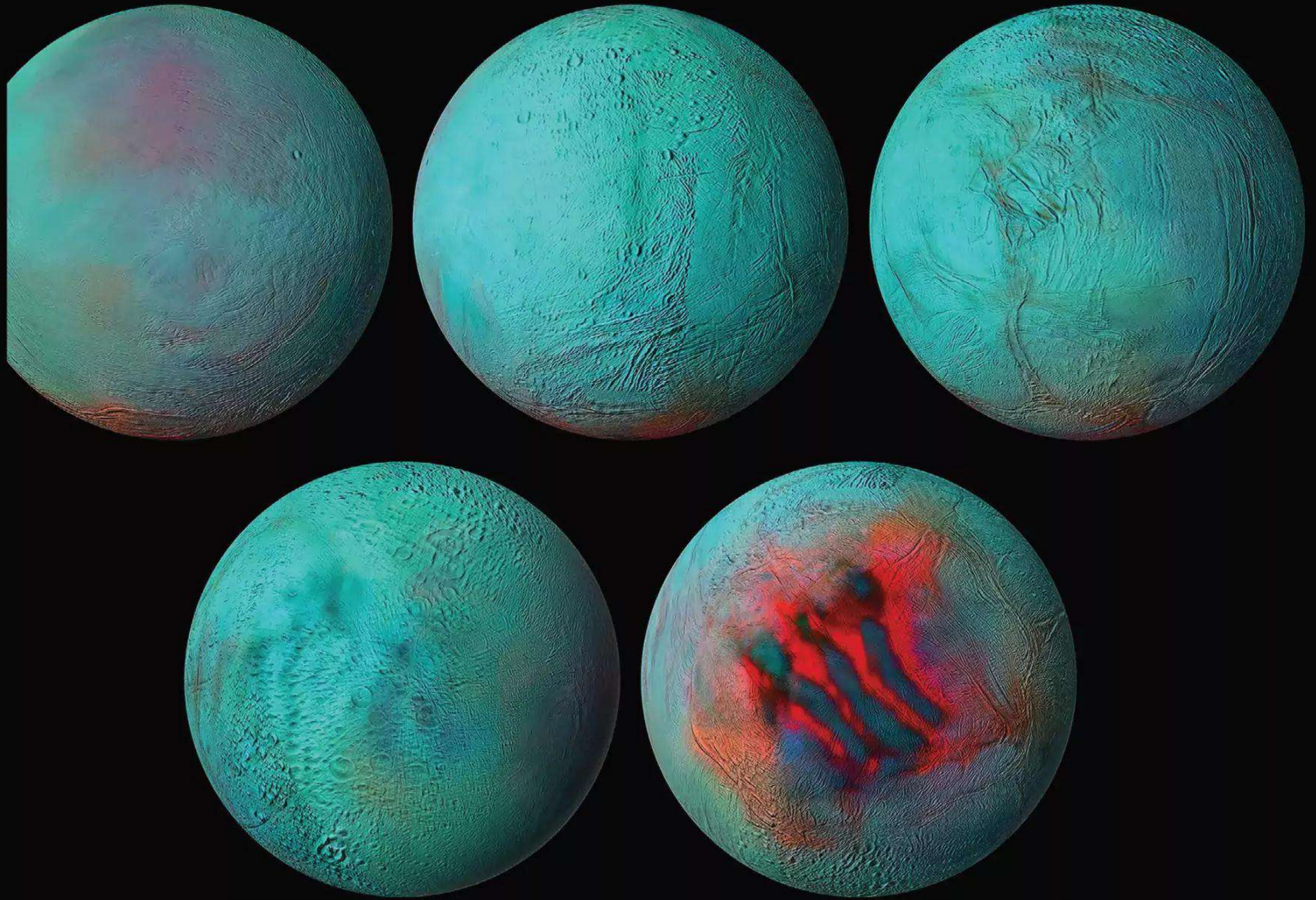
Jupiter and its moon Europa

On 25 August 2020, NASA/ESA's Hubble Space Telescope conducted its annual check-up on Jupiter leading astronomers to try and understand how the planet's turbulent atmosphere shifts and changes. In the same image is the gas giant's moon Europa but the interesting detail here is the bright-white storm that's travelling at 560 kilometres (350 miles) per hour at the mid-northern latitudes. Erupting on 18 August 2020, weather systems like this usually only pop up once every six years but this specimen offers the chance to study a young and evolving Jovian storm.

© NASA/ESA

Enceladus in infrared

Although NASA's Cassini spacecraft plunged to its death through Saturn's atmosphere on 15 September 2017, the data it collected is still instrumental in discovering more about the ringed planet and its satellites. Using the probe's Visible and Infrared Mapping Spectrometer (VIMS), Enceladus' surface was mapped from pole to pole. A notable feature of the moon is its south pole 'tiger stripes', and with the infrared details revealed in this image, Cassini's team has gained further knowledge of Enceladus' geological activity and surface ice movement.



The future of antennae

This is the European Space Agency's (ESA) prototype reflector antenna. With a diameter of 2.6 metres (8.5 feet), it is made of revolutionary metal-mesh. The design makes the antenna a lot less bulky over current models, less heavy and more mobile to allow for launch into space.

The AMPER (Advanced techniques for mesh reflector with improved radiation pattern performance) project is an European effort to adapt from traditional ground-based metal antennae to more lightweight structures that could one day be deployed into Earth orbit.

Catching a supernova

When a star explodes in space, astronomers try to turn multiple telescopes to the scene of the eruption as quickly as possible. The light intensity of a supernova peaks very quickly, and this spike needs to be captured and studied in order to get an in-depth understanding of stellar physics.

When the supernova SN 2018gv – seen as the bright-blue object in the lower left – went off in the spiral galaxy NGC 2525, located 70 million light years away, astronomers shifted the Hubble Space Telescope towards it to watch it. This image is just one in a time-lapse sequence, spanning over a year, of the bright burst slowly dimming.

The image of M87's black hole is helping test Einstein's famous theory

Physicists attempt to break the rules of gravity

Words by Rafi Letzter

A new test of Albert Einstein's theory of general relativity has proved the iconic physicist right again - this time by reanalysing the famous first-ever picture of a black hole, which was released in April 2019. That image of the supermassive black hole at the centre of galaxy Messier 87 is the first direct observation of a black hole's shadow - the imprint of the event horizon, a sphere around the black hole's singularity from which no light can escape. Einstein's theory predicts the size of the event horizon based on the mass of the black hole, and in April 2019 it was already clear that the shadow fits general relativity's prediction well. But now, using a new technique to analyse the image, the researchers who made the picture showed just how well the shadow fits the theory: 500 times better than any test of relativity done in our Solar System. That result puts tighter limits on any theory that would seek to reconcile general relativity, which describes the behaviour of massive celestial objects, with quantum mechanics, which predicts the behaviour of very small things.

General relativity's great accomplishment was to describe how gravity operates in the universe: how it pulls objects towards each other, how it warps space-time and how it forms

black holes. To test general relativity, scientists use the theory to predict how gravity will act in a certain situation. Then they observe what actually happens. If the prediction matches the observation, general relativity has passed its test.

But no test is perfect. Watch how the Sun's gravity tugs Mercury along its orbit and you can measure general relativity in action. But telescopes can't measure the movement of Mercury down to the nanometre. And other forces - the tug of Jupiter's gravity, and Earth's gravity and the force of the solar wind, to name just a few - impact Mercury's movement in ways that are difficult to separate from the effects of relativity. This means the result of every test is an approximation and Einstein's theory is only proven more or less.

The size of that uncertainty - the 'more or less' factor - is important. When scientists test general relativity over and over, they are putting constraints on Einstein's idea. The reason this work is important is that even though general

relativity keeps passing tests, physicists do expect it to eventually fail. General relativity must be incomplete, physicists believe, because it contradicts quantum mechanics.

In the new test, scientists used a computer to generate artificial images of the Messier 87 black hole based on a modified version of gravity, where the force of gravity is weaker or stronger at the event horizon. With that weakened-gravity scenario, they asked how large or small that black hole's event horizon would be. What about with stronger gravity? Then they checked how many of those possible modifications produced event horizons with sizes that matched that of the image actually captured of Messier 87. Some did, with their slight variances from general relativity's predictions much too small to show up in the admittedly fuzzy snap of the black hole. But the vast majority did not. Most alternative ways that gravity might work that they considered don't fit within this newly narrowed wiggle room.

"SCIENTISTS USE THE THEORY TO PREDICT HOW GRAVITY WILL ACT IN A CERTAIN SITUATION"



© ESO

Six galaxies found trapped around a supermassive black hole

Words by Elizabeth Howell

New data from the European Southern Observatory's (ESO) Very Large Telescope (VLT) in Chile and other observatories gives astronomers a sense of black hole evolution when the universe was less than a billion years old. One mystery of supermassive black holes is how they got so large, some containing billions of times the mass of the Sun. Supermassive black holes are also relatively common: they lurk at the hearts of most, if not all, galaxies, including our own Milky Way. The new observations give fuel to the idea that such black holes grow in gassy environments within large, web-like structures.

"This research was mainly driven by the desire to understand some of the most challenging astronomical objects - supermassive black

holes in the early universe," said Marco Mignoli, an astronomer at the National Institute for Astrophysics in Bologna, Italy. "These are extreme systems, and to date we have had no good explanation for their existence."

Mignoli said the half-dozen galaxies were found in a 'spider's web' of gas that stretches away from the black hole to a distance of 300 times the size of the Milky Way. The rich gas environment could explain why these black holes grew so quickly in the short time after the Big Bang.

The spider-web structures may have grown out of collections of dark matter, a poorly understood substance that makes up most of the matter in our universe, but can only be detected through its gravitational effects.

Star is seen being shredded by 'spaghettification'

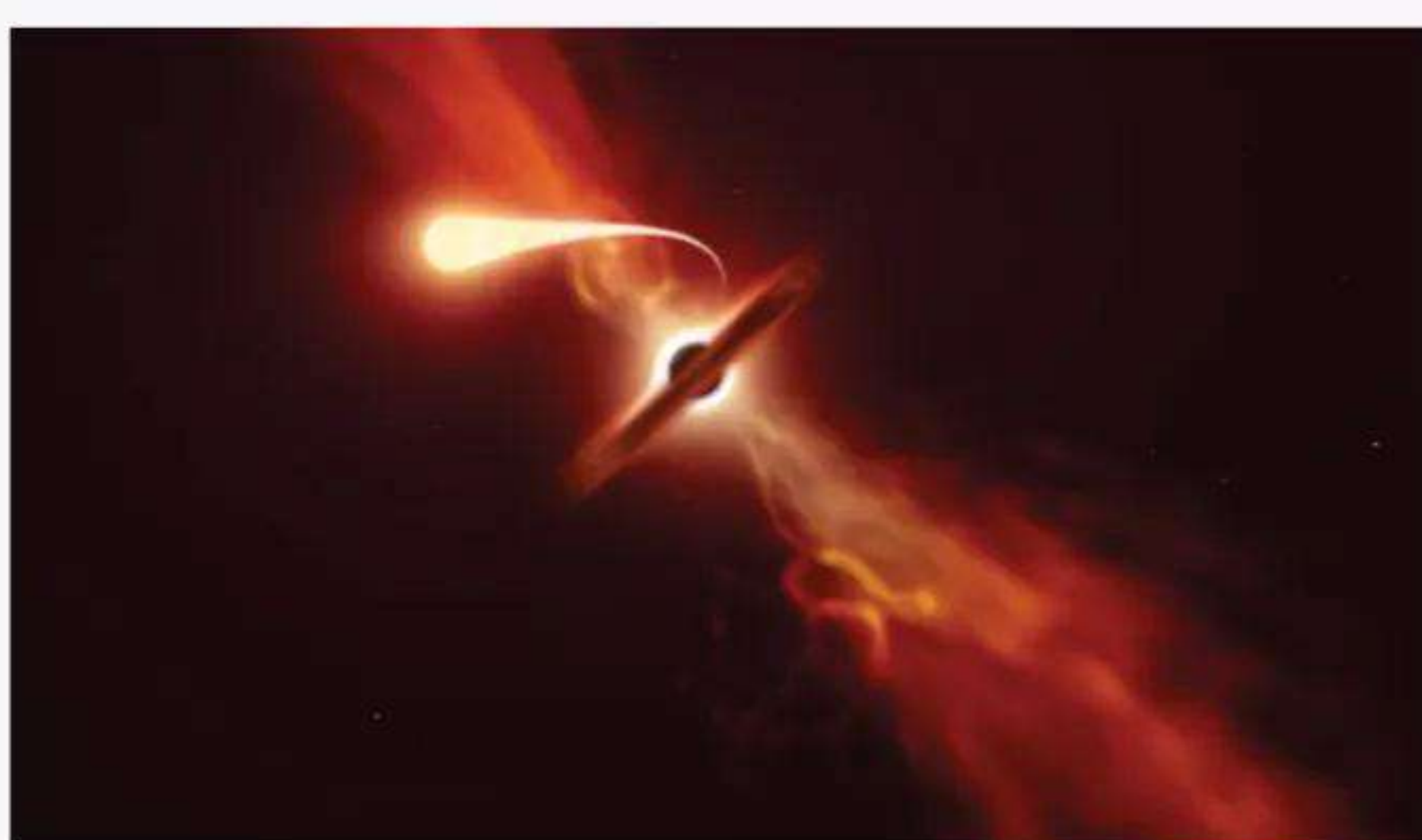
Words by Elizabeth Howell

Telescopes have captured the rare light flash from a dying star as it was ripped apart by a supermassive black hole. This rarely seen 'tidal disruption event' - which creates spaghettification in stars as they stretch and stretch - is the closest such known event to happen at only 215 million light years from Earth. One light year is the distance light travels in a year, equating to about 10 trillion kilometres (6 trillion miles). "The idea of a black hole 'sucking in' a nearby star sounds like

science fiction. But this is exactly what happens in a tidal disruption event," said Matt Nicholl, a lecturer and Royal Astronomical Society research fellow at the University of Birmingham, UK. Researchers caught the event in action using numerous telescopes, including the European Southern Observatory's (ESO) Very Large Telescope (VLT) and New Technology Telescope.

It has been difficult to see these events in the past because the black hole eating up the star has a tendency to shoot out material from the dying star, such as dust, that obscures the view. Luckily the newly studied event was studied shortly after the star was ripped to shreds.

Researchers studied the event, known as AT 2019qiz, over six months as the flare became bright and then faded away. Observations took place in ultraviolet, optical, X-ray and radio wavelengths. Looking at the event in this comprehensive way showed how the material leaves the star and the flare the star sends as its dying gasp.



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Asteroid Bennu's boulders shed new light on the space rock's history

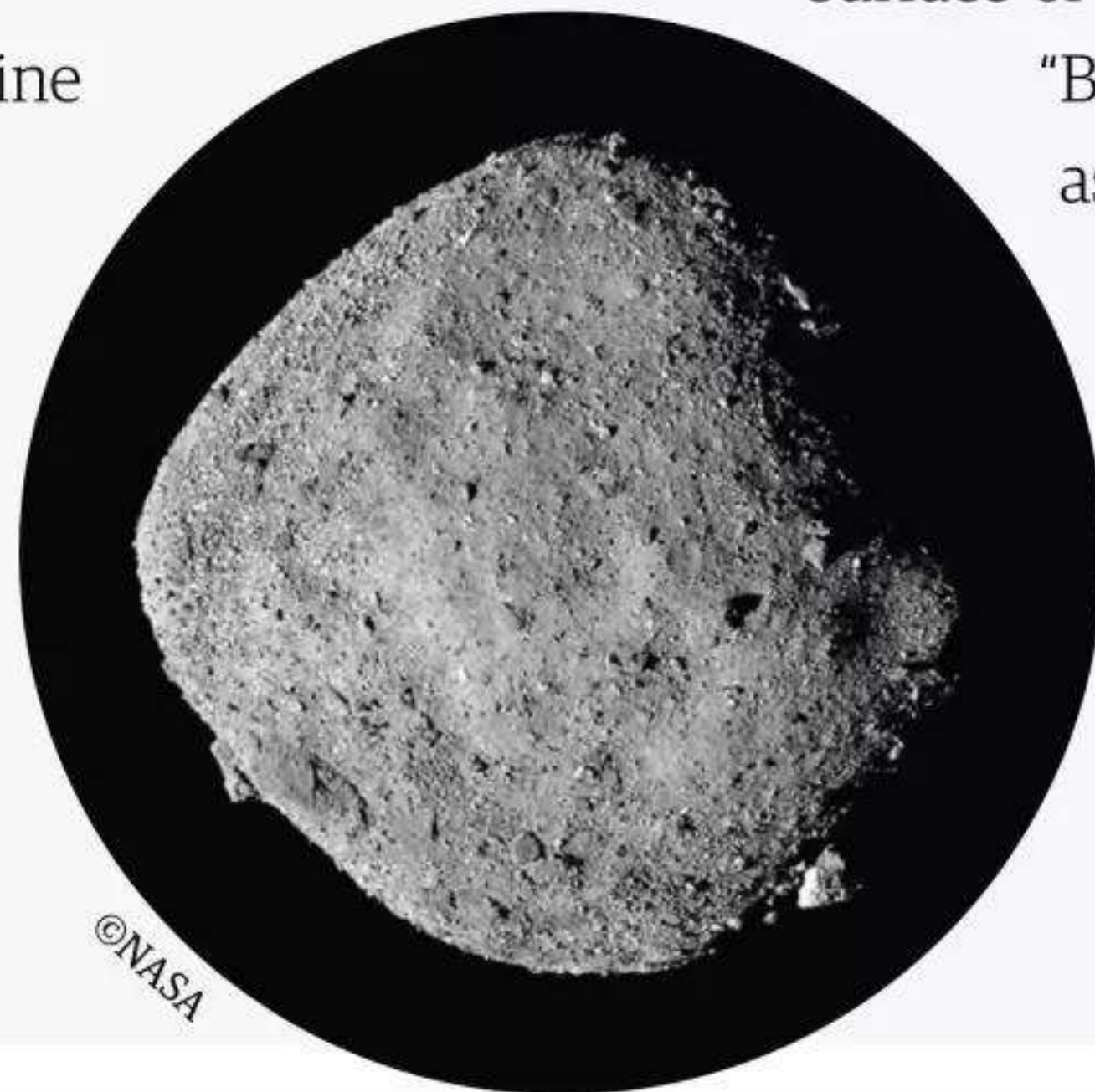
Words by Nola Taylor Redd

The near-Earth asteroid Bennu continues to reveal its secrets to NASA's OSIRIS-REx mission, which has been orbiting the space rock for nearly two years. New research reveals veins of carbonite materials in Bennu's boulders, as well as signs of organic minerals widespread across its surface. The variety of rock compositions on the asteroid's surface, the gravity of the asteroid and the unbalanced, diamond-shaped structure of the asteroid's body suggest that Bennu formed after the collision of two parent asteroids.

The new results provide a baseline for the samples that OSIRIS-REx will collect from Bennu's surface. The spacecraft is expected to bring those samples back to Earth in 2023 - if all goes according to plan - and will reveal not only insight about the asteroids that pass near our

planet, but also a glimpse of the first 10 million years after the Sun's formation.

In the process of building planets, the early Solar System also created a lot of debris that would never become a world. These leftovers have many of the same signatures of planetary building blocks but just didn't quite make it into the finished product during all the chaos. Many of these drifted to the asteroid belt, though some were hurled back towards Earth early on to deposit water on the surface of the then-dry planet.



"Because it migrated from the main asteroid belt into an Earth-crossing orbit, Bennu is a prime example of how material could have been delivered to the early Earth from farther out in the Solar System," said Amy Simon, a researcher at NASA's Goddard Flight Center in Maryland.

Left: OSIRIS-REx arrived at Bennu on 3 December 2018 and has been studying it ever since

Right: The ISS has been occupied for almost 20 years now

'Superflares' may make it hard for life to begin around dwarf stars

Words by Mike Wall

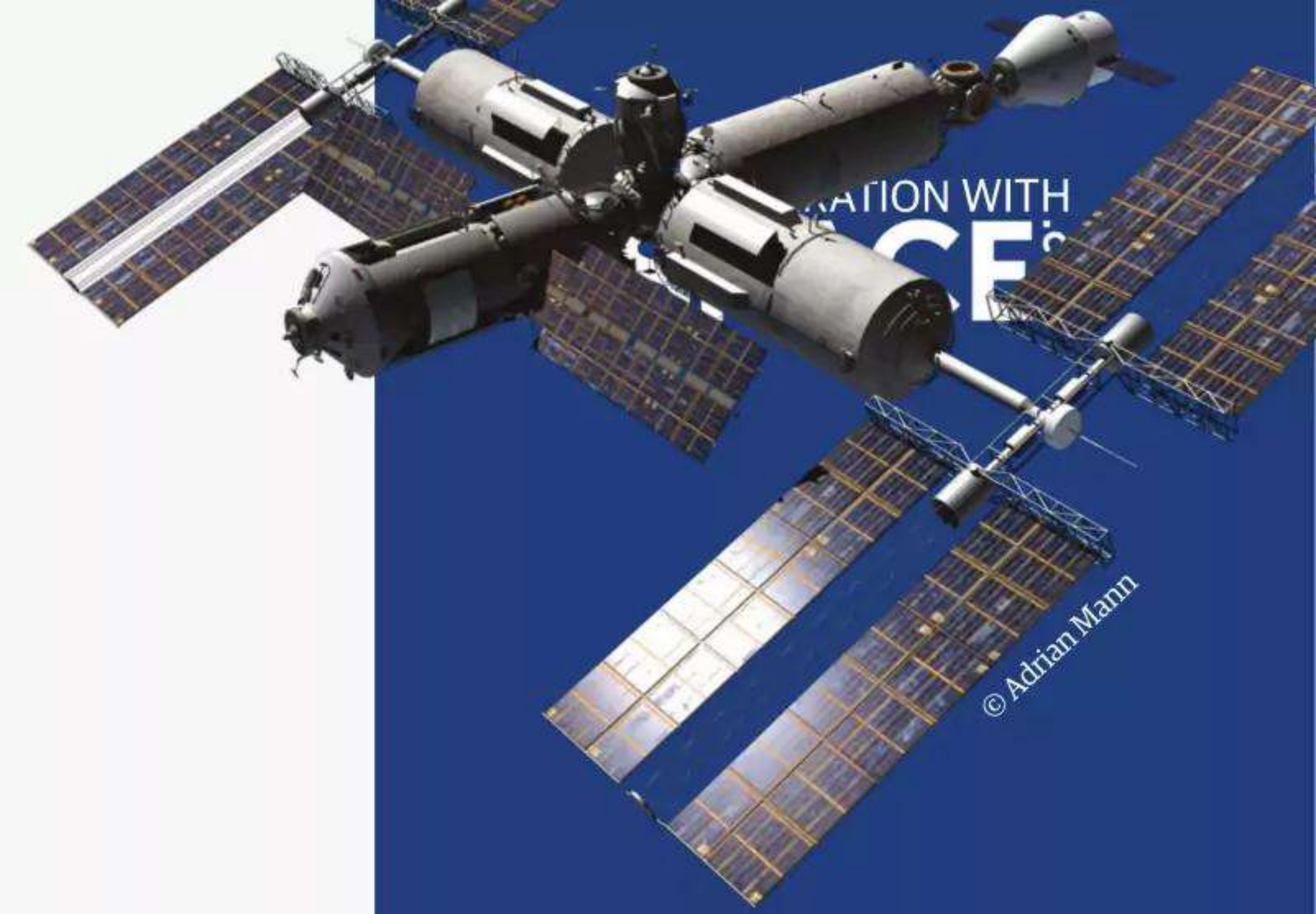
Powerful stellar eruptions could pose a serious challenge to the origin and evolution of life around the universe. Such outbursts throw off large amounts of ultraviolet (UV) radiation, which is not only directly harmful to life as we know it, but can also strip away the atmospheres of relatively close-orbiting planets. These issues are especially pronounced for worlds circling red dwarfs.

Red dwarfs are more active than Sun-like stars, especially when they're young. Because each red dwarf is so dim, their 'habitable zone' is much closer in. "We found planets orbiting young stars may experience life-prohibiting levels of UV radiation, although some microorganisms might survive," said Ward Howard, a doctoral student in the Department of Physics and Astronomy at the University of North Carolina (UNC), Chapel Hill.

Howard and his colleagues measured the temperatures of 42 superflares emitted by 27 red dwarfs. They did so by analysing observations made simultaneously by the Evryscope, an array of small telescopes at the Cerro Tololo Inter-American Observatory in Chile, and NASA's Transiting Exoplanet Survey Satellite, which has been hunting for alien worlds from Earth orbit since 2018.

These observations were obtained every two minutes, allowing the scientists to get an extremely detailed temperature profile across the brief life of the red-dwarf superflares, which typically emit most of their UV radiation during a 10- to 15-minute-long peak. Temperature is strongly correlated with UV emission, so the researchers were then able to estimate the radiation loads imposed by the outbursts.

Below: Planets around red dwarfs might not be great for life's emergence



Cosmonauts patch air leak on the ISS

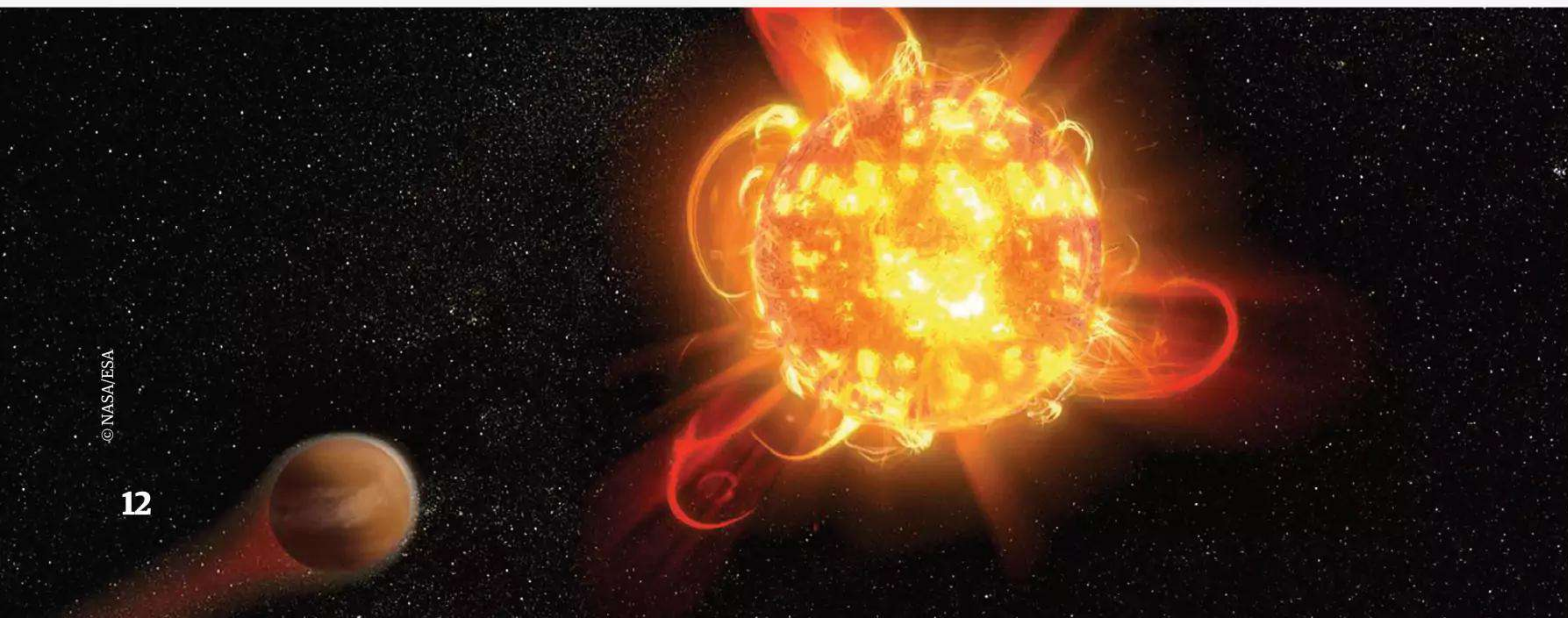
Words by Meghan Bartels

Cosmonauts are making progress in the fight against the small air leak that has beleaguered the International Space Station (ISS) for months. The leak was first detected in September 2019 but was too low a priority for NASA and Roscosmos to address until August of this year given the short staffing and high activity rates at the orbiting laboratory.

In August NASA announced a few measures that Roscosmos was undertaking to track down the leak's location. Those steps included two crew weekend sleepovers on the Russian segment to isolate components of the station. At no point has the leak threatened the space station or the astronauts living on it.

Cosmonauts report that they tracked down the leak on 15 October and attempted to patch it. The leak is located in a compartment of the Russian Zvezda module, as previous work on the orbiting laboratory had suggested.

Russian cosmonaut Ivan Vagner, who has been living in the facility since April, called it a 'scratch', which also suggested the crew used a tea bag to track down the precise location of the leak, but did not provide additional details about the process. "Perhaps we should try hard patches our partners have? We can talk with them. This is because the current patch is not so efficient," the cosmonauts said.



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The other part of the prize is a £200 gift voucher to Kielder Observatory, located in Northumberland, UK, which can be exchanged for six adult tickets to one of the observatory's main events on any weekend. These vouchers will be valid for 12 months from the deadline of this competition, as per the terms and conditions, giving you the flexibility of when you want to cash in on an amazing night of astronomical marvels.



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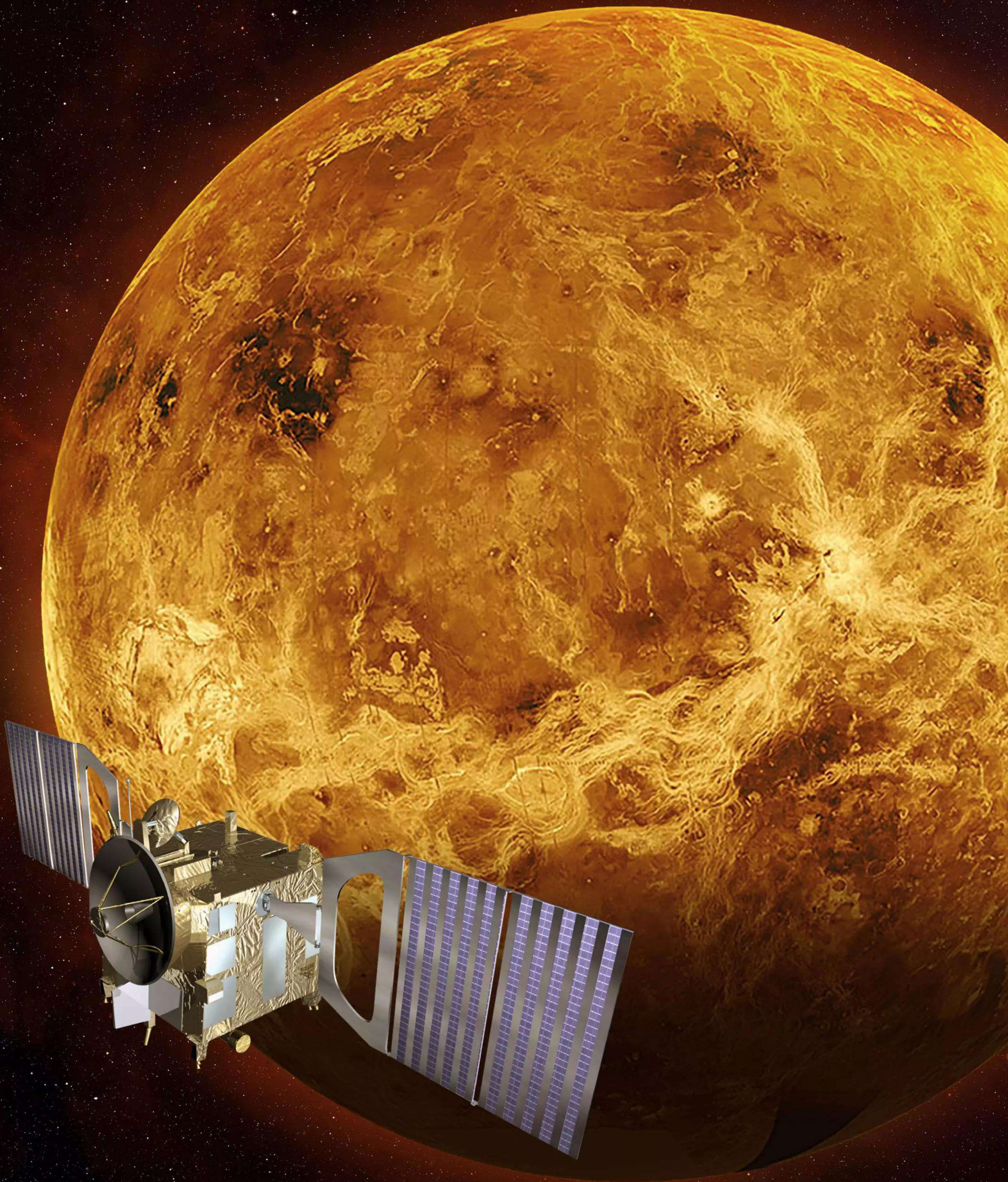
What is the largest moon in the Solar System?

A: The Moon **B:** Ganymede **C:** Titan

Competition ends on 3 December 2020

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IS THERE LIFE ON VENUS?

A discovery in the cloud decks of the hostile planet
could be the smoking gun for astrobiologists

Reported by Lee Cavendish

EARTH V

Sometimes called 'Earth's Twin', Venus

AVERAGE DISTANCE FROM THE SUN

150 MILLION KILOMETRES (93 MILLION MILES)

PLANET RADIUS

6,378 KILOMETRES (3,963 MILES)

PLANET DENSITY

5,520 KILOGRAMS PER CUBIC METRE

SURFACE TEMPERATURE

15 DEGREES CELSIUS (59 DEGREES FAHRENHEIT)

ATMOSPHERIC COMPOSITION

78% NITROGEN, 21% OXYGEN, 1% ARGON

Could life be floating around in the clouds of Venus? Does Earth's sister planet have habitable conditions above the hellscape that is its surface? Have astrobiologists just found another target in the Solar System they should be investigating? These are just some of the questions that have recently come to attention after research led by Professor Jane Greaves of Cardiff University found phosphine, a potential biosignature, in the atmosphere of Venus.

Phosphine - a molecule made up of one phosphorus atom and three hydrogen atoms - is a rare find. It can be created through chemical reactions on gas giant planets, as well as being produced industrially on Earth as a fumigant, in the semiconductor-manufacturing industry and as a by-product of the illegal production of methamphetamine. On Earth it can also be created biologically by microbes that live in oxygen-free environments. As this gas is a known by-product of biological processes, also known as a biosignature, it has fuelled intense speculation about what could be hiding on the second rock from the Sun.

Although the surface of Venus is extremely toxic and unforgiving, laced in a thick atmosphere of 96 per cent carbon dioxide and clouds consisting of sulphuric acid, there are more similarities to Earth than you may think. Venus is 80 per cent the mass of Earth and 95 per cent the radius, making them relatively alike on a planetary scale. They are both rocky planets that have a surface composition consisting of basalt rock and altered minerals.

If you could jump back in time 3 or 4 billion years, Venus would be a lot cooler and a lot wetter, potentially accommodating oceans of liquid water inside a hospitable atmosphere. However, this all changed when the planet experienced

a greenhouse runaway effect that insulated the planet's atmosphere and trapped more of the Sun's heat. This has resulted in the surface that can be observed today, with temperatures of 465 degrees Celsius (869 degrees Fahrenheit) and pressures similar to if you were diving roughly 910 metres (3,000 feet) under the sea on Earth.

"It's thought that much earlier in Venus' history, the surface was much cooler and wetter, and life could have possibly originated. But conditions turned very hostile," says Greaves. "But there is a long-standing theory that the smallest forms of life - these microorganisms - might have been able to evolve upwards into the high clouds."

"MUCH EARLIER IN VENUS' HISTORY, THE SURFACE WAS MUCH COOLER AND WETTER, AND LIFE COULD HAVE POSSIBLY ORIGINATED" JANE GREAVES

SO VENUS

Life on Venus

is in fact a very different world to ours

AVERAGE DISTANCE FROM THE SUN

108 MILLION KILOMETRES (67 MILLION MILES)

PLANET RADIUS

6,052 KILOMETRES (3,760 MILES)

PLANET DENSITY

5,250 KILOGRAMS PER CUBIC METRE

SURFACE TEMPERATURE

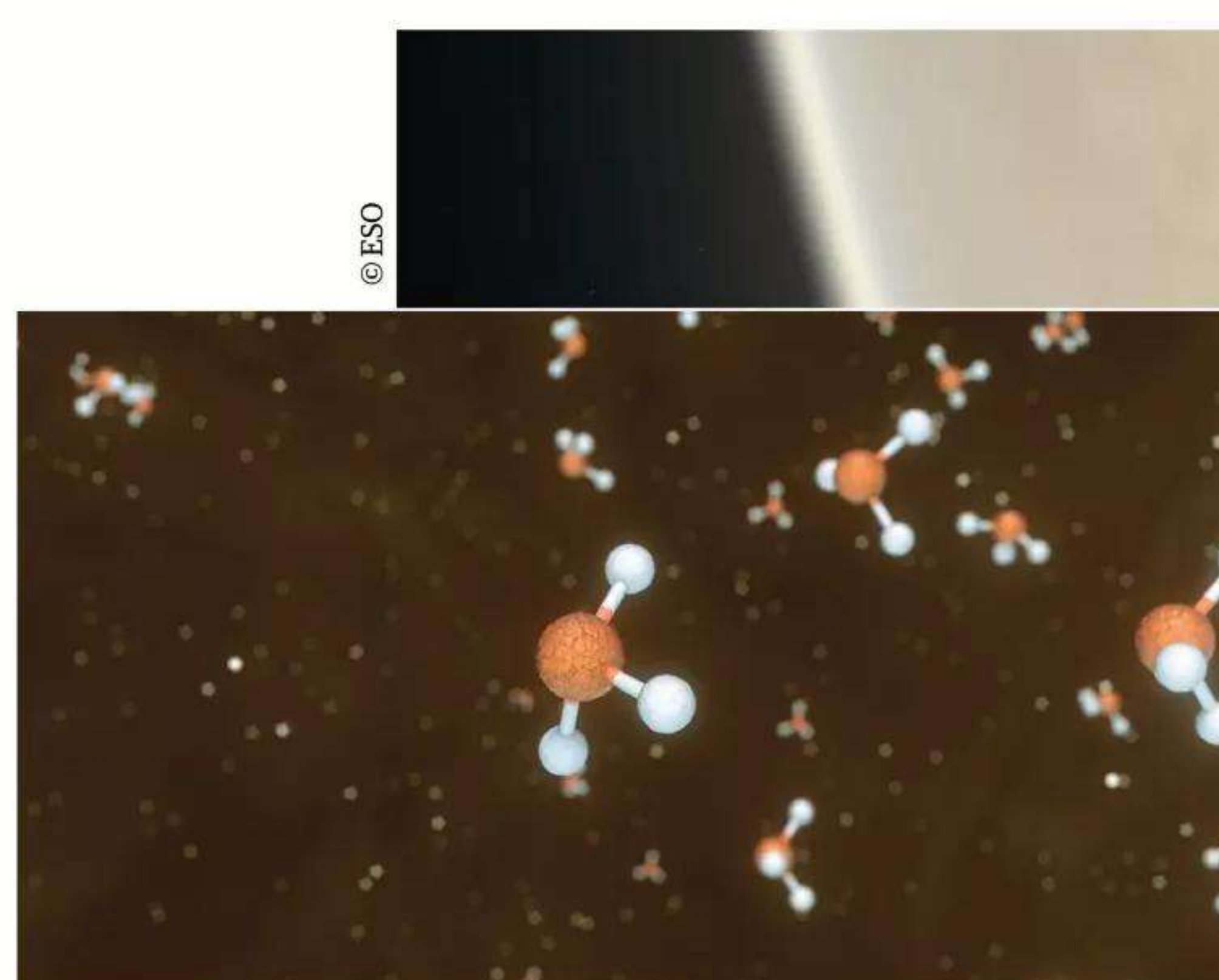
465 DEGREES CELSIUS (869 DEGREES FAHRENHEIT)

ATMOSPHERIC COMPOSITION

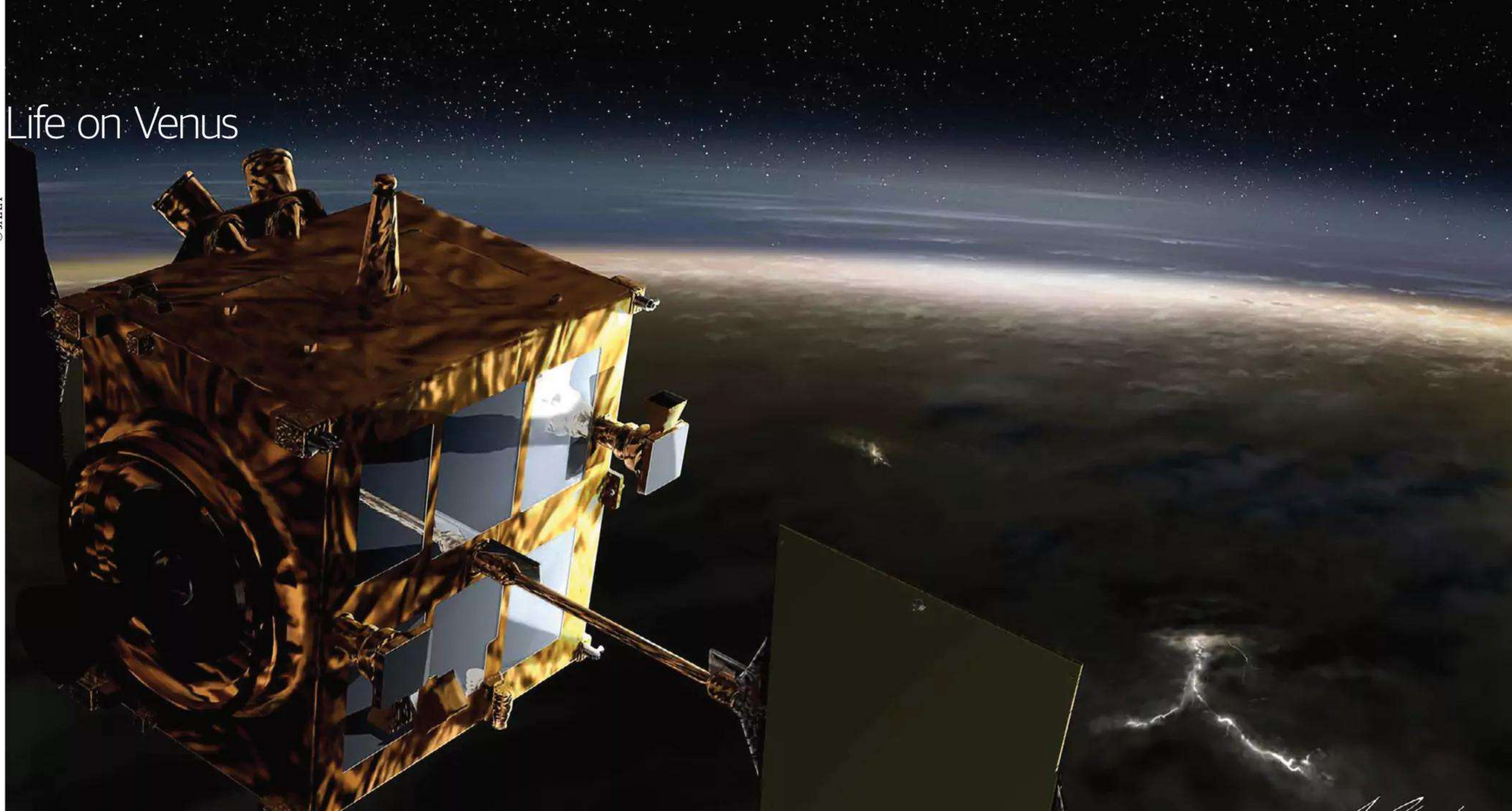
96% CARBON DIOXIDE, 3% NITROGEN

This discovery by Greaves originated as “an experiment made out of pure curiosity.” Now it has the world talking about Venus being a possible host for life. The first course of action in making this discovery began with Greaves utilising the power of the James Clerk Maxwell Telescope (JCMT) at Mauna Kea Observatory in Hawaii, which specialises in submillimetre-wavelength observations. The JCMT was able to capture the light of Venus and perform a spectroscopic analysis of the planet, where astronomers identify a specific molecule in its atmospheric composition based on if there is an absorption or emission of radiation at a specific wavelength. This is where the first sign of phosphine was found.

“Due to the exceptional and unexpected detection of phosphine with the JCMT, although this was good data, Professor Greaves decided to get confirmation from ALMA [the Atacama Large Millimeter/submillimeter Array] to make absolutely sure,” explains Dr Anita Richards of the UK ALMA Regional Centre and the University of Manchester to **All About Space**. “Also, while as a single



Right: This artist's impression depicts phosphine - one phosphorus and three hydrogen atoms - drifting in Venus' atmosphere



telescope the JCMT just sees Venus as a single blob, ALMA can see details of Venus on a similar scale as the eye can see the Moon."

This allowed the team to upgrade from the single lens of the JCMT, which has a primary mirror diameter of 15 metres (49 feet), to an array of 45 telescopes, each with a mirror diameter of 12 metres (39 feet). Since ALMA is situated in the cloudless and dry desert of Chile, it provides much more meticulous and detailed observations. Using ALMA, the same absorption dip in the spectrum was seen at the 1.123-millimetre wavelength. "Given that we did this with two completely independent observatories, what we can say with very high confidence is that we have detected phosphine on Venus. This is very exciting and was really quite unexpected," says Greaves.

Further analysis has shown that phosphine is present in an extremely low abundance: there are approximately 20 molecules for every billion other molecules. The ALMA data was also able to derive that the signal is coming from an altitude of roughly 50 to 60 kilometres (31 to 37 miles). "If you're talking about 50 to 60 kilometres up, then the pressure is much like it is at the surface of Earth, and the temperature is quite nice - maybe up to 30 degrees Celsius, or 85 degrees Fahrenheit - so it's been hypothesised that this is a living habitat today," says Greaves.

After the detection became more of a certainty, the question moved to 'how did it get there?' "We do not know. We are confident that what we know about Venus cannot make phosphine in the amounts we see, so something we do not know must be making it," says Dr William Bains of the Massachusetts Institute of Technology to **All About Space**. Before the idea of microbial life can become a viable answer, all the known chemical processes

"WE HAVE DETECTED THE PHOSPHINE ON VENUS. THIS IS VERY EXCITING AND WAS REALLY QUITE UNEXPECTED" JANE GREAVES

of Venus must be accounted for. Or, as Bains puts it: "A general rule in astrobiology is that life is an explanation of last resort. When you have ruled out everything else, then you say maybe it's life."

To start crossing possible answers off the list, the team began with investigating whether there is a photochemical process going on in the upper atmosphere of Venus that could be producing phosphine. Photochemistry is where molecules are broken down after being hit with the Sun's ultraviolet light and react with other elements to form new molecules, which is the same mechanism that creates Earth's ozone. This was not fruitful.

Next they examined if there were reactions that occur in the clouds and lower atmosphere, using thermodynamics calculations, that could account

for this quantity of phosphine, but again this research did not account for the detection. Then came the question of whether there was chemistry occurring within the rocks on the surface that could be creating the phosphine and erupting it into the atmosphere. "Rock calculations using thermodynamics suggested that yes, volcanoes could produce tiny traces of phosphine, but it would be parts per quadrillion in the atmosphere, not 20 parts per billion," says Bains.

For the sake of diligence the team then looked at the possibility that the phosphine is being replenished through less obvious chemical processes. Some examples include being formed by a lightning strike, or meteorites delivering minerals that then react with Venus' atmosphere to create

Above: Japan's Akatsuki is the only active spacecraft currently in orbit around Venus

Right: Life has been found latched onto hydrothermal vents at the bottom of Earth's oceans - an unlikely location



phosphine. Analyses showed that the production rates for these other potential mechanisms still fall short by a factor of millions. "That really left us with two possibilities. The first is that there is some completely unknown and exotic - and therefore very exciting - chemistry going on in the clouds of Venus," says Bains. "Or, and this is the more exciting one, that the phosphine is being produced by life."

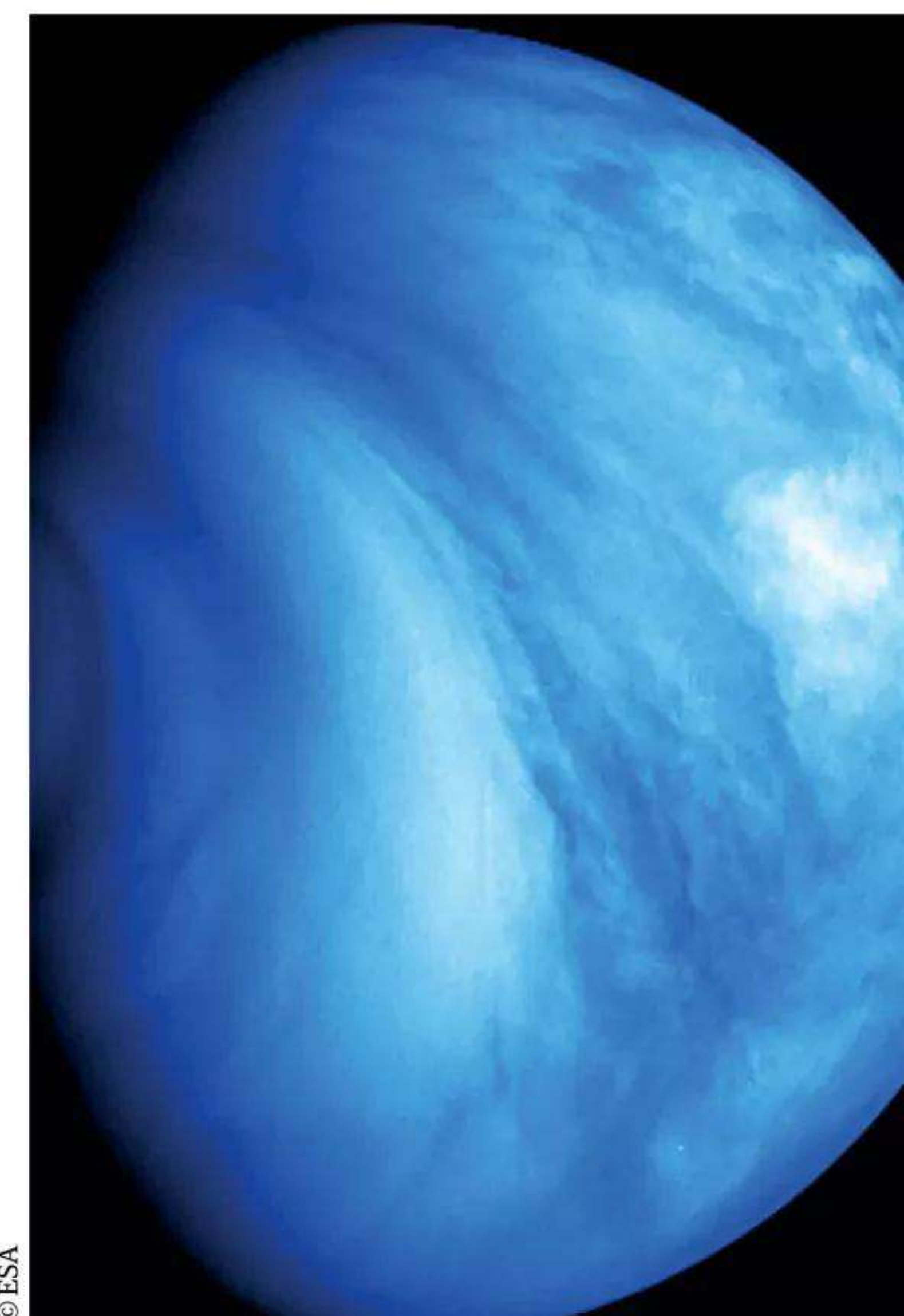
While this claim is surrounded in scepticism and a lack of direct evidence, there is now weight behind this argument. As Greaves has stated, there has been a long-standing theory that there are microorganisms lingering in the clouds of Venus, and it was also noted in the scientific paper, published in *Nature Astronomy*, that organisms on Earth only need to work at ten per cent of their maximum productivity to produce the observed quantity of phosphine.

Life already exists in the clouds of Earth as

tiny bacteria that absorb water vapour and form cloud droplets and ice nuclei, which are vital for precipitation, so it's not a rogue idea that microbial life could be sitting in the clouds, but there is an issue with the composition of Venus' clouds. Venusian clouds are made up mostly of sulphuric acid - this is extremely acidic, and harmful for life as we know it. However, biologists have found many different types of life that thrive in the most unlikely of places, called extremophiles.

As an example, astronomers are extremely intrigued by the biology that thrives on Earth's hydrothermal vents, cracks in the seabed that leak geothermal heat and chemical substances, which some aquatic life survives on. The reason astronomers are so interested in these vents is because they show that life can be found in some of the harshest regions on Earth, so who is to say that there can't be extremophiles in the clouds of Venus

Right: Venus is viewed here in ultraviolet by the European Space Agency's Venus Express



© ESA

HOW THE DETECTION WAS MADE

Two observatories in Hawaii and Chile were used to find phosphine's spectral signature

1 STARTING WITH THE JCMT

This discovery was made by performing a spectroscopic analysis of Venus' atmosphere using the JCMT in Hawaii, which is operated by the East Asian Observatory. The objective was to intentionally search for phosphine, a potential biosignature, in the planet's thick atmosphere.

2 THE FIRST HINT OF PHOSPHINE

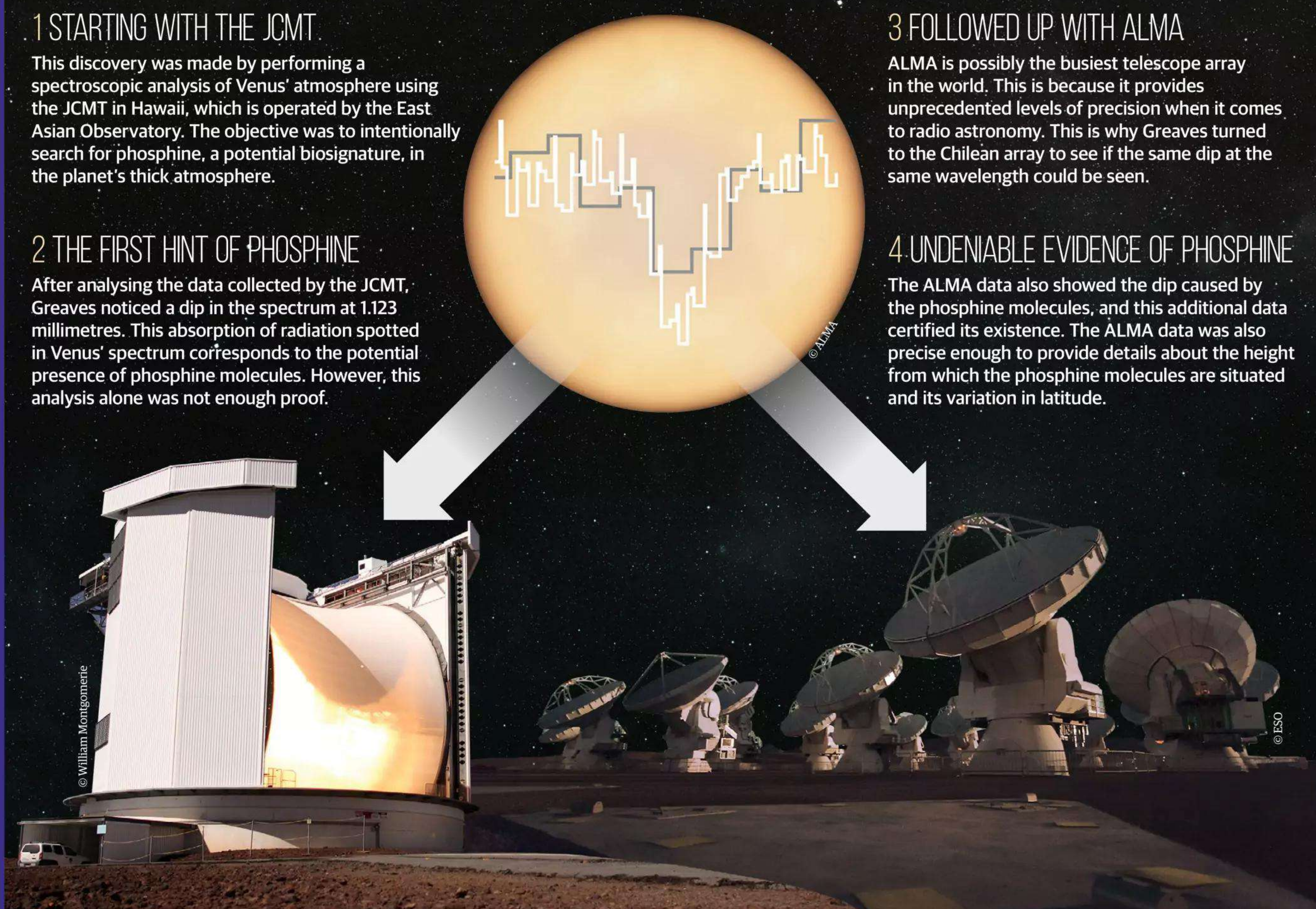
After analysing the data collected by the JCMT, Greaves noticed a dip in the spectrum at 1.123 millimetres. This absorption of radiation spotted in Venus' spectrum corresponds to the potential presence of phosphine molecules. However, this analysis alone was not enough proof.

3 FOLLOWED UP WITH ALMA

ALMA is possibly the busiest telescope array in the world. This is because it provides unprecedented levels of precision when it comes to radio astronomy. This is why Greaves turned to the Chilean array to see if the same dip at the same wavelength could be seen.

4 UNDENIABLE EVIDENCE OF PHOSPHINE

The ALMA data also showed the dip caused by the phosphine molecules, and this additional data certified its existence. The ALMA data was also precise enough to provide details about the height from which the phosphine molecules are situated and its variation in latitude.



WHAT COULD THE FUTURE HOLD FOR THE EXPLORATION OF VENUS?

With this recharged interest in Venus, here are some upcoming mission ideas that could return even more groundbreaking results

VENERA-D

This mission concept has already been under development for around five years, and its aim is to deliver an orbiter, a lander – similar to the Soviet's Vega space probe – and one long-life surface station. This will provide data not just about the planet's atmosphere, but also the surface and interior.

VERITAS

NASA's Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy, (VERITAS) mission is being considered as the next space exploration mission under NASA's Discovery Program. If chosen, VERITAS will map the surface of Venus and look to understand how it evolved into a world completely different from Earth.

COLONIES IN THE CLOUDS

This is certainly an idea that won't be attempted by the current crop of astronauts, but there have been conceptual ideas – bordering on science-fiction – that suggest colonies could be established in the clouds of Venus. This would provide an unrivalled opportunity to collect samples and detect direct evidence for alien microbial life.

DRONES

Soon drones will be flying through the atmospheres of Mars (Ingenuity helicopter) and Titan (Dragonfly). Why not have drones hitching a ride on the thick and rapid clouds of Venus as well? This could be the most efficient and effective way to gain in-situ observations of the planet's upper atmosphere.

that have developed an evolutionary trait where they use the sulphuric acid as an energy source? The recent phosphine discovery has added more fuel to the fire, and this was all done using ground-based telescopes.

Exploration of Venus pales in comparison with our other neighbouring world, Mars. It has been criminally underinvestigated, even though based on the planets' semi-major axis distances Venus is closer to Earth than Mars by approximately 37 million kilometres (26 million miles). In the early 1960s, when the Soviet Union and the United States were engulfed in the Space Race, many spacecraft were launched to Venus under different programs as the two heavyweights went head to head. Punches were thrown in the form of the US' Mariner program and the Soviet's Zond and Venera programs. However, this was seemingly more out of competition than scientific discovery.

The Soviets even managed soft landings with their Venera landers, the first and most famous being Venera 7, but surface conditions were too hostile, and craft only survived for roughly 30 minutes. Technologies and rocketry have evolved immensely over the last several decades, yet the only spacecraft currently in orbit around Venus is the Japan Aerospace Exploration Agency's (JAXA) Akatsuki spacecraft. Other spacecraft are planning to fly by Venus and collect scientific data, including the Parker Solar Probe, the BepiColombo mission to Mercury and the Solar Orbiter, but observing Venus is not their primary objective.

With increased momentum now surrounding the exploration of Venus, astronomers, astrobiologists, engineers and mission decision makers are now seriously considering sending more missions there. Bains believes that there could even be a sample mission on the horizon on the back of this discovery. "I cannot imagine a sample-return mission before 2030. It would need a program, building up to a vehicle that could descend, hang around, sample and re-orbit and then return. What does it sample? Does it need to collect a few droplets or a bucket-load? From the lower haze layer or just the top of the clouds? Or both?" he asks. "A mission to fly into the clouds and analyse them - just to get an idea of what the sample mission should be sampling - is, my guess, not going to get to Venus before 2030, so 2035 at the earliest, assuming there was an Apollo-style push to do it."

However, there are some upcoming missions which could see the US and Russia return to Venus. NASA has proposed an orbiter called VERITAS that will look to understand how the planet's geodynamics have shaped its history and how this differed from Earth's. The Russian space agency Roscosmos has proposed its own mission, called Venera-D, which will consist of two main modules, an orbiter and a lander, that will study the planet's atmospheric composition and properties up to an altitude of around 60 kilometres (37 miles), as well

"WHAT WE KNOW ABOUT VENUS CANNOT MAKE PHOSPHINE IN THE AMOUNTS WE SEE, SO SOMETHING WE DO NOT KNOW MUST BE MAKING IT" WILLIAM BAINS

as other aspects about the planet's surface and internal structure.

More futuristic and innovative responses have been talked about in the recent past. Astronomers and engineers have been developing new ideas that include drones gliding through Venus' clouds. In June 2018 NASA partnered up with Black Swift Technologies, an aerospace company in Boulder, Colorado, with the intention of building a drone capable of surviving and surveying the extraterrestrial clouds. In an even more futuristic vision of exploration, there have also been discussions about whether humans could build colonies in the clouds, something reminiscent of Bespin's Cloud City in *Star Wars*.

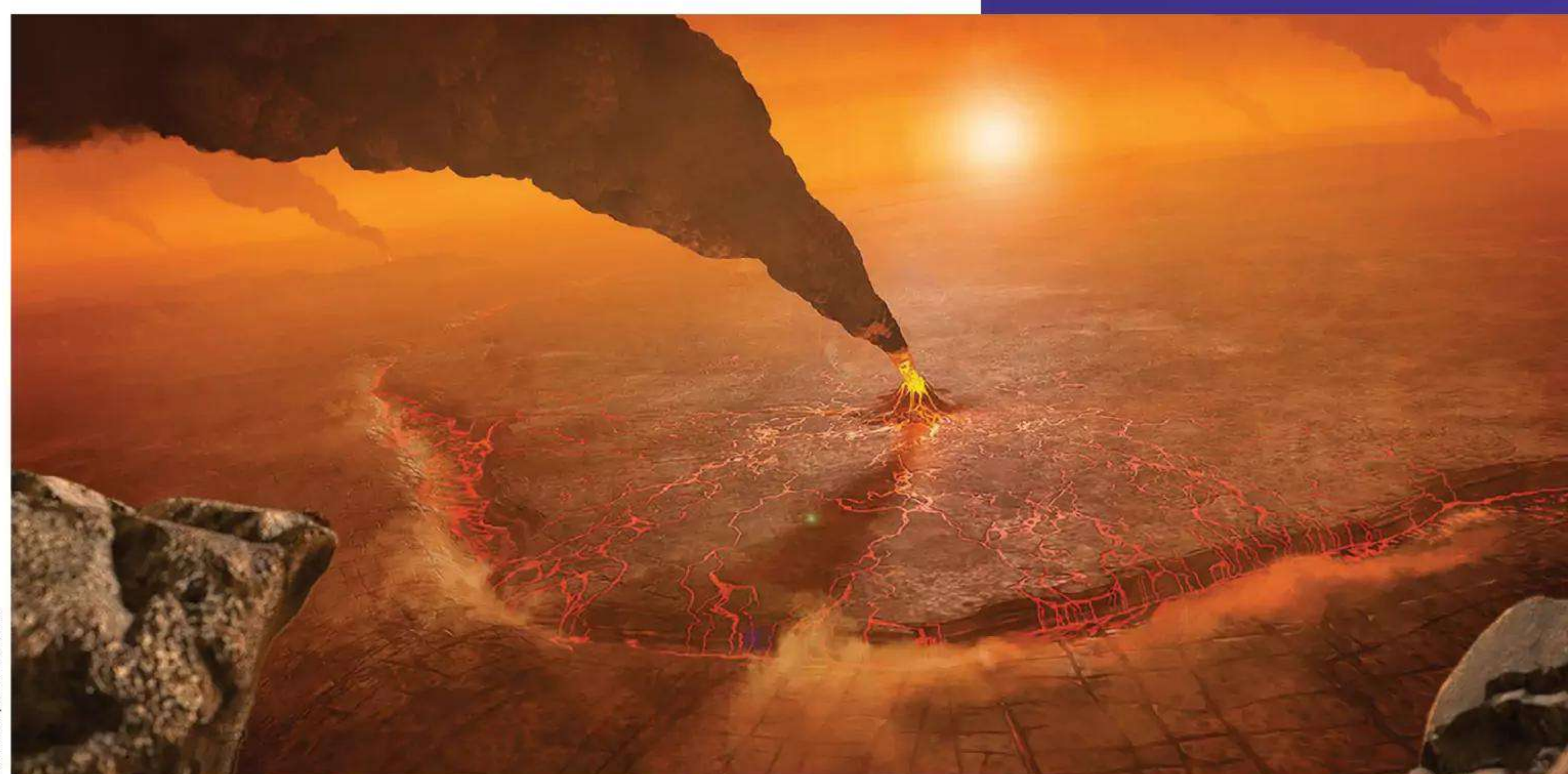
In essence, this discovery may be looked back on in 20 years' time in the same way that astronomers nowadays look back on the discovery of Martian meteorite ALH84001. This provided tantalising results that life may exist - or have existed - on the Red Planet, and has since seen a fleet of rovers, landers and satellites sent there. Each mission has been motivated by the bacterial evidence found within ALH84001 and has continued to yield incredible results. With motivation now at an all-time high for the exploration of Venus, there are only new, exciting discoveries left to come.



Lee Cavendish
Staff Writer

Lee holds a degree in observational astronomy, which has given him the knowledge to discuss the latest complexities of the universe.

Below:
Venusian volcanoes erupt phosphine into the atmosphere in small amounts, but not enough to account for 20 parts per billion



© NASA/JPL-Caltech

THE ASTROBIOLOGIST'S HIT LIST

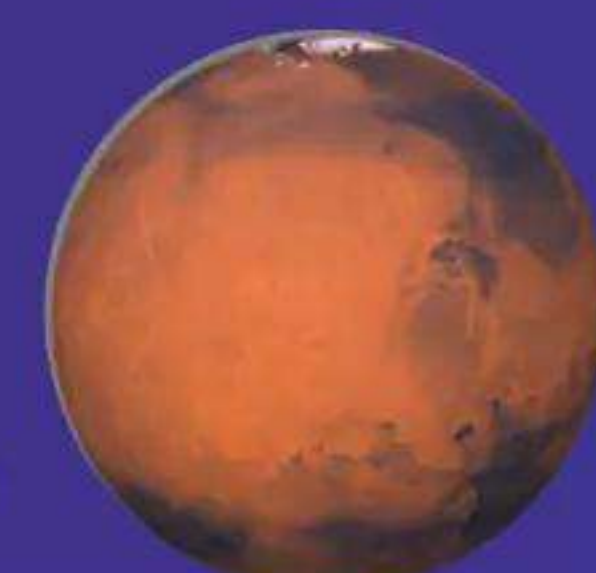
VENUS

After this incredible phosphine discovery, the cloud layers of Venus have become another contender for astrobiological inspection.



MARS

Mars has been a target for landers, rovers and satellites for many years as astrobiologists look to deduce if ancient life ever existed on the Red Planet.



EUROPA

Jupiter's moon Europa appears to have a warm and salty subsurface ocean, ideal environmental parameters for supporting potential alien aquatic life.



ENCELADUS

Similar to Europa, Saturn's moon Enceladus has a potentially hospitable subsurface ocean. However, astrobiologists know more about Enceladus thanks to NASA's Cassini mission.



TITAN

Another of Saturn's moons, Titan is a world filled with rich organic compounds, which are known building blocks for life as we know it.



ATHLETE

If we are to settle on other planets in the Solar System, we will need machines for heavy lifting in all manner of environments. NASA is working on such a robot already

1 Multiple limbs

Six identical limbs provide support and manipulation for ATHLETE, giving six degrees of freedom: three motions and three rotations for the wheels and tools at the tips.

2 Central chassis

Constructed as either a single hexagon or two connecting triangles, the central chassis is the base for the six limbs and would carry the cargo or exploration payload.

5 Grappling

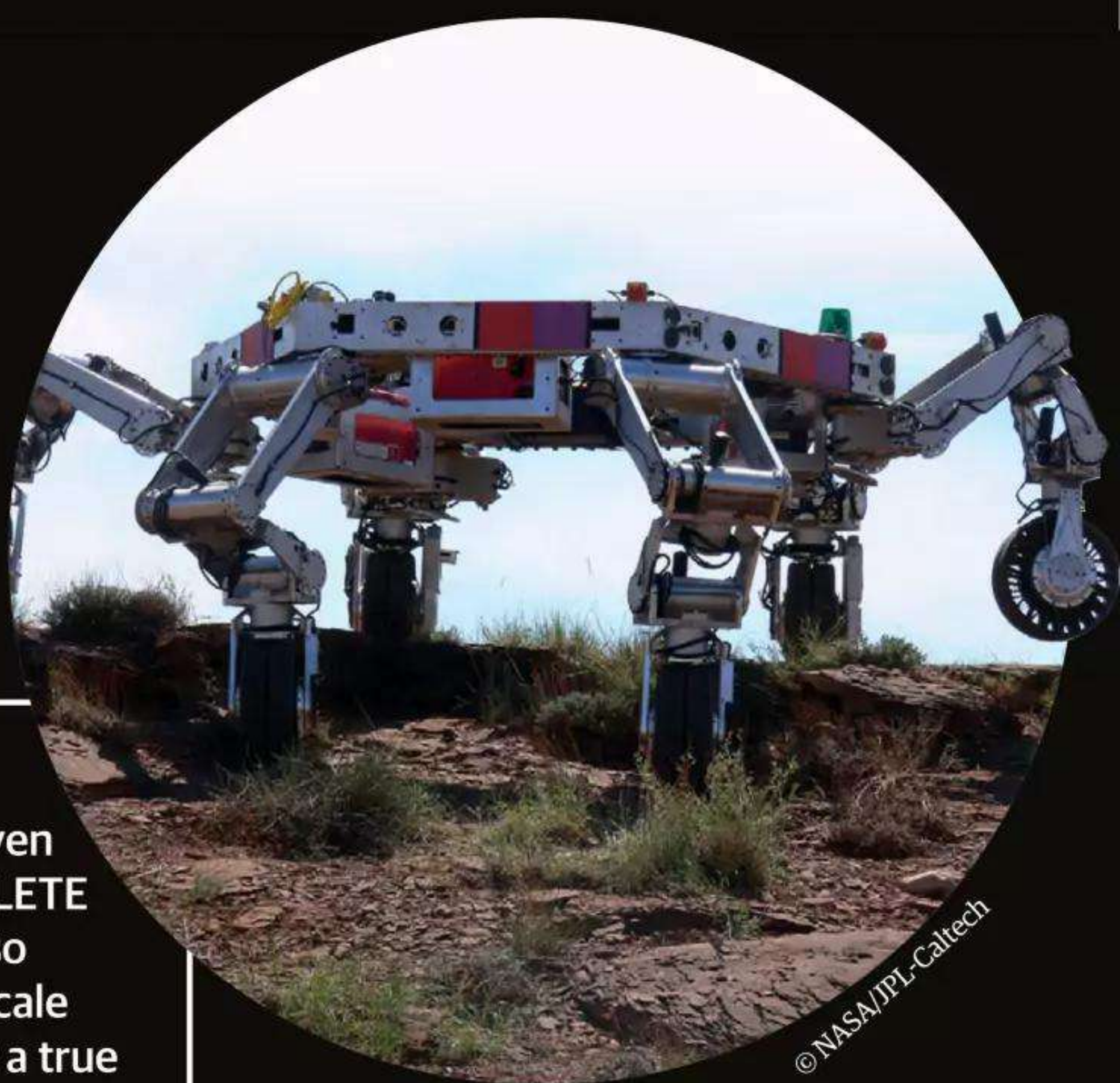
JPL engineers have even looked at equipping ATHLETE with a grappling system so that it would be able to scale vertical terrain, making it a true go-anywhere robot.

3 Tools

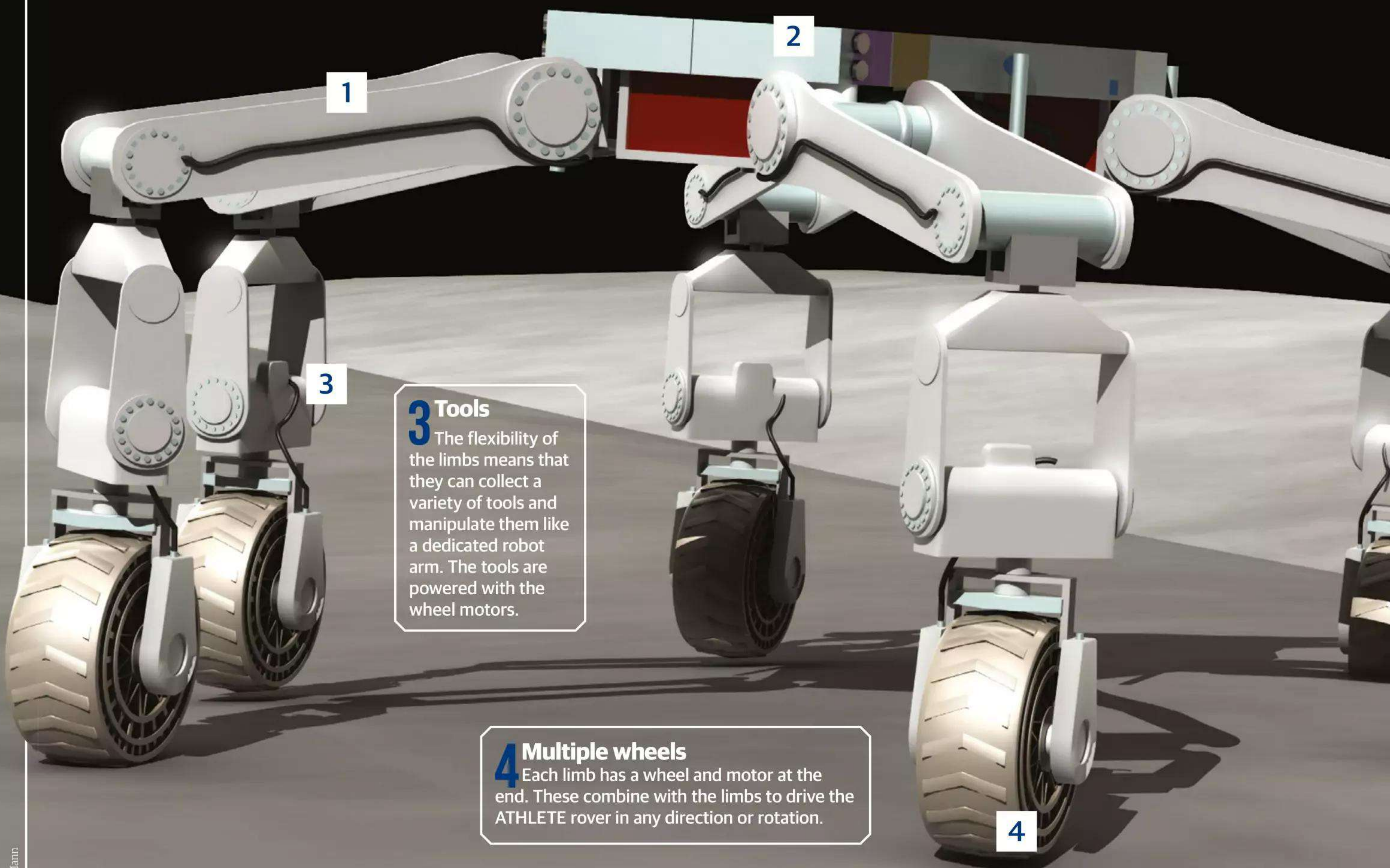
The flexibility of the limbs means that they can collect a variety of tools and manipulate them like a dedicated robot arm. The tools are powered with the wheel motors.

4 Multiple wheels

Each limb has a wheel and motor at the end. These combine with the limbs to drive the ATHLETE rover in any direction or rotation.



© NASA/JPL-Caltech



The All-Terrain Hex-Limbed Extra-Terrestrial Explorer, or ATHLETE, is NASA's concept for a heavy-lift utility robot to help human exploration by carrying loads over long distances. Starting in 2005, the project has built and tested two generations based around an ingenious multipurpose structure. ATHLETE has six limbs fixed around a central ring. The limbs have multiple joints that allow the ends to be moved back and forth, up and down, side to side and angled around all three axes as well.

Each limb has a wheel on the end with its own electric motor, so ATHLETE can drive in any direction, rotate around any point or even lock the wheels and walk. The limbs also provide the ability to lift and lower the central ring, so an ATHLETE could drive up to a cargo lander, lift off the module, cart it over to its desired location - regardless of terrain - and install it.

ATHLETE's skills go beyond heavy lifting though; as the limbs are full robotic arms, they are designed so that the ends can collect various tools from the central chassis and then drive them with the wheel motors. These could be drills, scoops, grippers or any other tool useful for the task at hand, so the design could be used for exploration robots too.

"ATHLETE COULD DRIVE UP TO A CARGO LANDER, LIFT OFF THE MODULE, CART IT OVER TO ITS DESIRED LOCATION - REGARDLESS OF TERRAIN - AND INSTALL IT"

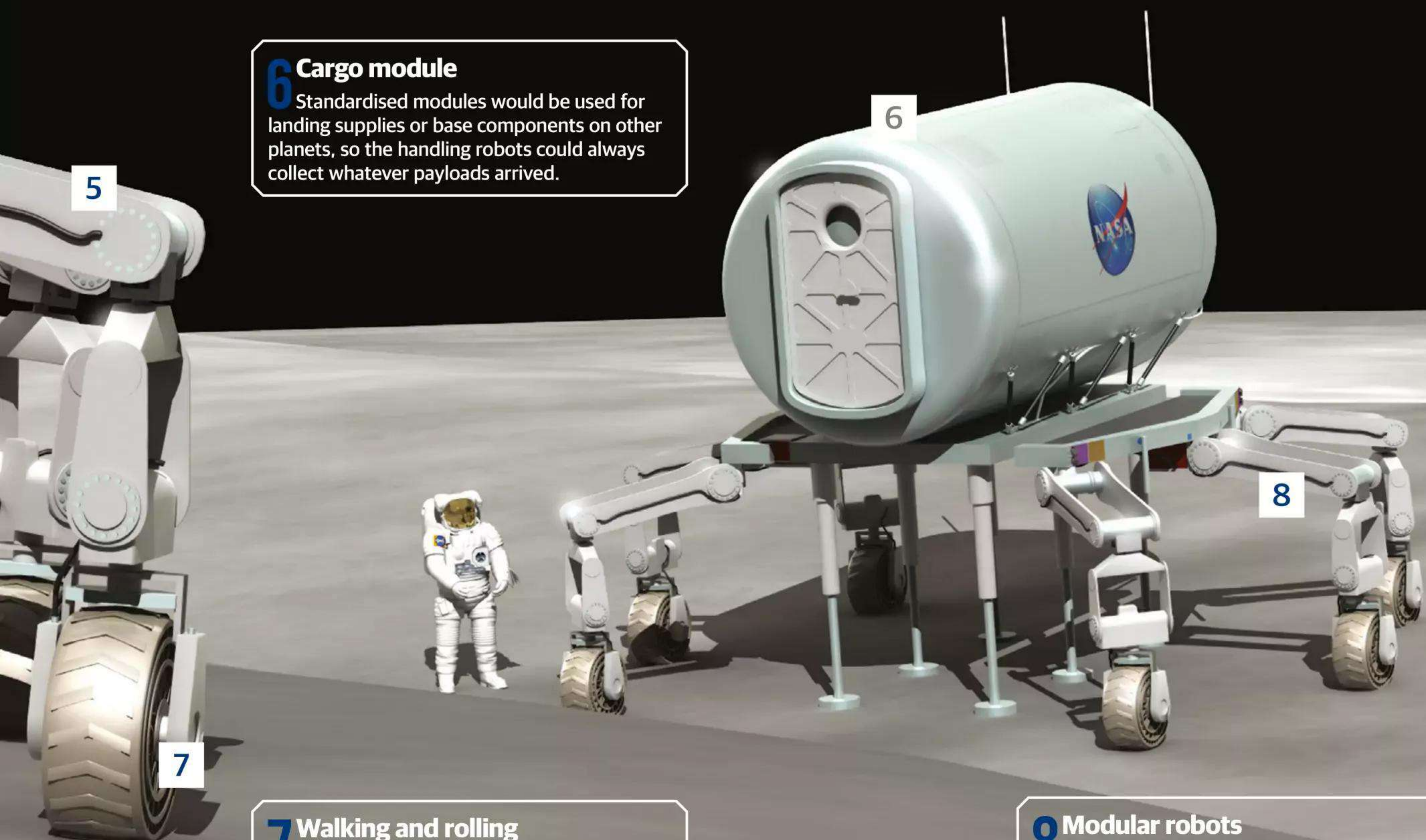
Placing any payload on another planet is very expensive, and missions are always vulnerable to unforeseen conditions or breakdowns. ATHLETE's multipurpose limbs could reduce the mass of a rover by combining the propulsion and steering systems with the exploration tools. Its ability to walk could get it into and out of terrain that wheels alone couldn't manage, which also means the wheels and motors can be smaller and lighter. Also, the interchangeable capability of the six arms means a mission would be able to continue in the event of several breakages.

NASA has taken the modularity of the design even further with the second-generation ATHLETES, referred to as Tri-ATHLETES. The hexagonal chassis has been split into two three-legged robots that can join together to form a complete ATHLETE. This could further ease the handling of cargo modules, as the two Tri-ATHLETES can approach a module from either

side without having to first drive over the top of it as a singular ATHLETE would.

The first version of ATHLETE, built by NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, began testing in 2005 and can lift 1,800 kilograms (3,968 pounds) on the Moon or 900 kilograms (1,984 pounds) on Mars. The two-part Tri-ATHLETES were built in 2009 and can lift 2,700 kilograms (5,952 pounds) on the Moon and 1,350 kilograms (2,976 pounds) on the surface of Mars.

Both generations have undergone extensive testing, and the program continues to expand the robot's capabilities. The shape of ATHLETE means that multiple robots could be stacked for launch, and with NASA's renewed focus on a human mission to Mars in the 2030s, ATHLETE-like robots will very likely be a part of constructing the habitats we need, most likely before humans even travel to the planet.



6 Cargo module

Standardised modules would be used for landing supplies or base components on other planets, so the handling robots could always collect whatever payloads arrived.

7 Walking and rolling

ATHLETE can use small wheels for rolling along smooth terrain, or it can lock the wheels to walk through soft or rocky ground.

8 Modular robots

Depending on the mission, ATHLETES can be constructed as one single six-limbed device or two three-limbed ones that are able to work together.

INTERVIEW BIO

Robert Yowell

Robert Yowell served as a technical consultant on the set of *The Right Stuff*. His knowledge and experience came from working as an engineer for NASA, beginning in 1989 and lasting over 11 years. Afterwards he had roles as director of The Aerospace Corporation and as a senior mission manager for SpaceX, as well as multiple roles within the US Air Force.

© Jeff Kravitz

THE RIGHT STUFF EXCLUSIVE

“WE WOULD NOT HAVE GONE TO THE MOON WITHOUT PROJECT MERCURY”

With an exciting new series about Project Mercury landing on Disney+, **All About Space** speaks to the show's technical consultant, Robert Yowell, about bringing his space engineering expertise to the show

Interviewed by Lee Cavendish

What experience do you have with NASA and space exploration missions? What were your roles in the past?

Primarily the Space Shuttle program. I was 22 in 1989; NASA hired me right out of college. I worked at the Johnson Space Center in Houston [Texas]. For the first two years there my primary responsibility was developing the onboard computer displays for Space Shuttle missions, which were carrying various payloads into orbit. My first job was to support the STS-46 mission, which flew about three years later in 1992. In 1989 I developed the onboard display to deploy a European satellite that was called EURECA [European Retrievable Carrier]. And I worked with the first Swiss astronaut Claude Nicollier, who flew on that Space Shuttle mission.

Two years after that I was actually selected to become a flight controller in Mission Control in Houston, and it took about a year or so of training. I became a flight controller in charge of communication systems on the Space Shuttle. My job was, among other things, to command and control the video cameras. There were six cameras inside the cargo bay of the Space Shuttle, and especially on missions where the crews had asleep periods, I had full control of those cameras. I could pan, tilt and zoom in to my heart's desire, and it sort of kept us all awake in the control centre as we

could fly over various parts of the world because the shuttle's cargo bay was always pointed towards Earth. We could zoom in on Kilauea volcano in Hawaii as we're flying over it, or the night lights of Rome or what have you. That was the fun part of the job, but the other part of the job required the guarantee that we could always talk to the Space Shuttle and they could talk to us.

My job was also to operate a tape recorder on the Space Shuttle, sort of like a black box, but even more so than that. In the gaps of time that we didn't have communications with the Space Shuttle, these tape recorders would always be recording. If we missed something like, let's say, some piece of equipment fails during the time we didn't have communication, we could go back and replay those recorders and see all the data that occurred. I supported about two dozen Space Shuttle missions, from 1991 through to around 1998.

You're a technical consultant on *The Right Stuff*. Is your main responsibility to make things as authentic as possible?

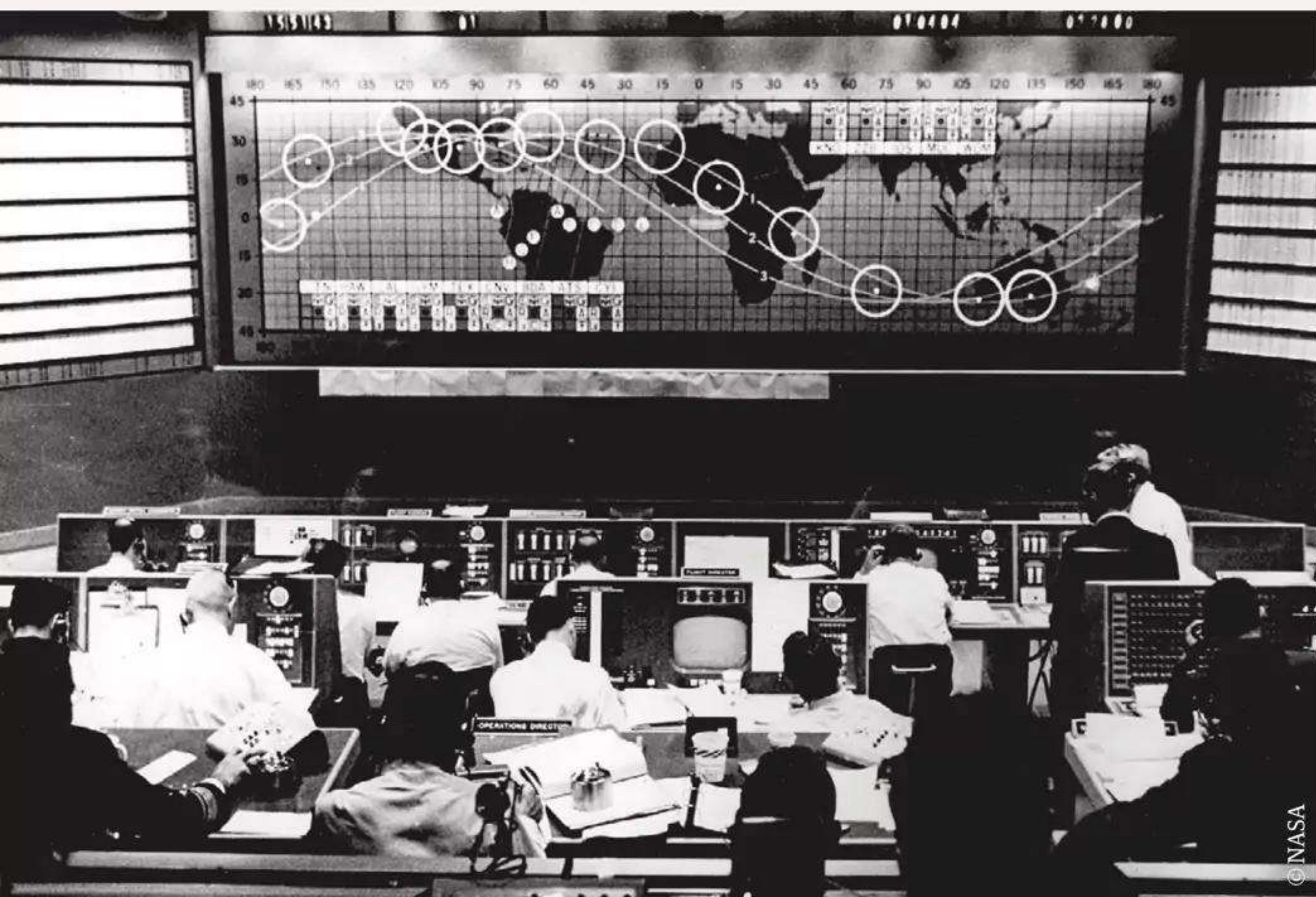
Absolutely correct, yes.

How were the experiences that you had with the Space Shuttle helpful when it came to depicting the US space program of the early 1960s?

Particularly in this season, you're going to see a focus on Mercury's control centre. Back in Project Mercury, it was Florida that housed the control centre, not Houston. The studio and production team did a tremendous job in recreating that very control centre, down to the floor tile, if you will.

More importantly, my job was to make sure it was explained to the actors, to the directors, exactly what was going on. In those days they did not have nearly the amount of data or the amount of equipment that we had, obviously in the Space Shuttle era, or even for Apollo. One of the primary tools in that control centre for Mercury was something called a 'strip chart recorder'. If you're familiar with that needle with ink on graph paper moving around like when you're getting your heart rate taken, just think of that as a way of measuring every parameter on the space capsule - or at least as many as they had at the time.

They didn't have, in Project Mercury, a video screen with digital data reading out numbers. What you'll see in the series is those video screens that were in the control centre were mainly for television, so they could see live pictures of the launch pad and watch. That was the extent of it, but later on in the Space Shuttle and the Apollo program, we did see all kinds of digital data, but not in those days. They relied heavily on what I call



Above: A photograph of NASA's Mission Control, taken in 1962

Right: *Life* magazine's cover on 14 October 1959: the Mercury astronauts

Left: Yowell worked on over 24 Space Shuttle missions during his 11 years at NASA



true analogue systems like the strip chart recorders. That was one of the things I helped explain in the making of the series.

Are there any aspects of the Mercury program that are not really common knowledge, but you think were incredibly influential?

In the overall Mercury program, sure. There were several things I would imagine that the public weren't fully aware of at the time. Thanks to many authors, not just Tom Wolfe, but the astronauts themselves, each wrote their own biographies eventually, or had someone write their biographies, if they weren't autobiographies.

I think the data is already out there for someone to research today, if they really wanted to know. There isn't anything that strikes me as off, something that's not already been described in various books or in compilations. Looking back it was certainly a very tenuous time in the US, with the Cold War and Cuba and all of that happening in the background. It's amazing to step back and

realise with all of that pressure going on that we were able to still have this program executed. It's really an amazing thing to look back on.

The Mercury program has been described as 'America's first reality show'. Would you agree?

I guess it was a different time back then, so not in the sense that it was on television. It was really *Life* magazine, the American weekly publication, that I believe at that time had a circulation of maybe 10 million, which was quite high for that time. That is where, if you will, you had the reality show aspect, because they did interview the families, the wives, the children, that sort of thing. In that sense these men were the most scrutinised pilots since [Charles] Lindbergh, for sure. From that perspective you could call it - maybe - a reality show, but certainly not at all to the degree that we think of reality shows today by comparison.

NASA is currently working on the Space Launch System, and it's doing really well in its tests.

How does this compare to the Mercury-Redstone Launch Vehicle?

Oh, it's no comparison. The Mercury-Redstone Launch Vehicle had a maximum thrust of 78,000 pounds [350 kilonewtons], so think of this: if you're familiar with the Saturn V rocket that took astronauts to the Moon, it had a launch escape tower at the very top of that rocket whose sole purpose was to take the Apollo Command Module off the rest of the massive rocket in an emergency situation. That escape rocket on top of the Saturn V had almost twice the thrust of the Mercury-Redstone. That was just the escape rocket. Not to mention the fact that the entire Saturn V was several million pounds of thrust. The Mercury-Redstone was a firecracker compared to any other rocket that the US has ever put a human on.

It's amazing when you think that the US went from the Mercury-Redstone Launch Vehicle to the Saturn V rocket in about ten years...

Not even ten years. From the day of Alan Shepard's

“IN THOSE DAYS THEY DID NOT HAVE NEARLY THE AMOUNT OF DATA OR THE AMOUNT OF EQUIPMENT THAT WE HAD”

flight to the day that we first launched the Saturn V unmanned, which was in 1967 – that’s less than six years. We first put astronauts on the Saturn V in 1968 when we sent Apollo 8 around the Moon. That’s just over seven years from Alan Shepard’s first flight.

You also had an advisory role on the 2019 science-fiction film *Ad Astra*, a story of astronauts travelling to Neptune. What was it like working on a series that is looking back in time and depicting the inception of space exploration, as opposed to the futuristic film?

For me it was really a special treat, because I consider myself an amateur historian on the space program. I think I was about four years old when I started really getting into this. I was watching the Apollo 15 mission in 1971 when I had the spark ignited in my interest in space exploration. For my entire life since I’ve lived and breathed it every moment, and certainly I’ve read a lot about the history of it. I was fortunate to have worked for NASA and been around in the late 1980s and 1990s with many of the engineers who worked on Apollo, so I’ve absorbed a lot of that history over time. To be able to contribute to a series like this is certainly a very special honour and privilege. I just hope that this contributes to people’s knowledge about this great period of American history.

The Mercury program is arguably as influential as the Apollo missions, but is not talked about as much. Would you agree?

I’d say the film, *The Right Stuff*, in the 1980s certainly helped ignite that interest, as well as, of course, the book, so I wouldn’t say there wasn’t interest. There’s always been interest in it. I think the series is going to do a great job in re-igniting the interest. I think it’s going to do a great job of showing the evolution, because we would not have gone to the Moon without Project Mercury.

It’s really important to understand the roots of all of the American space programs, and understand that the spirit that those seven astronauts brought is still alive today. We may not only be flying test pilots anymore, but the fact of the matter is flying into space is still a risky endeavour. It’s not routine. It’s not getting on an airliner. It still takes bravery and it takes a good level of intelligence to be able to operate in space.

Were there specific requirements or characteristics that the Mercury Seven astronauts had to have?

There were certainly discreet requirements for the original seven Mercury astronauts. They all had to be less than 40 years old. There was a height restriction, 5 foot 11 inches [1.8 metres], because of the size of the capsule. They all had to be graduates of Test Pilot School, and they had to have at least 1,500 hours of flight time and a bachelor’s degree.

Those were very stringent requirements. There weren’t thousands and thousands of people in the US that were graduates from Test Pilot School – there were maybe hundreds – but this type of requirement greatly limited the number of people who could have applied to be the original seven. Those requirements, over time, of course, have changed. It was actually in the late-1960s, in the Apollo program, that the Test Pilot School graduate requirement was removed. Around 1966 the very first American scientist-astronauts were selected, and a few of them actually did fly to the Moon. Most notably was Jack Schmitt, who walked on the Moon on the final Apollo mission.

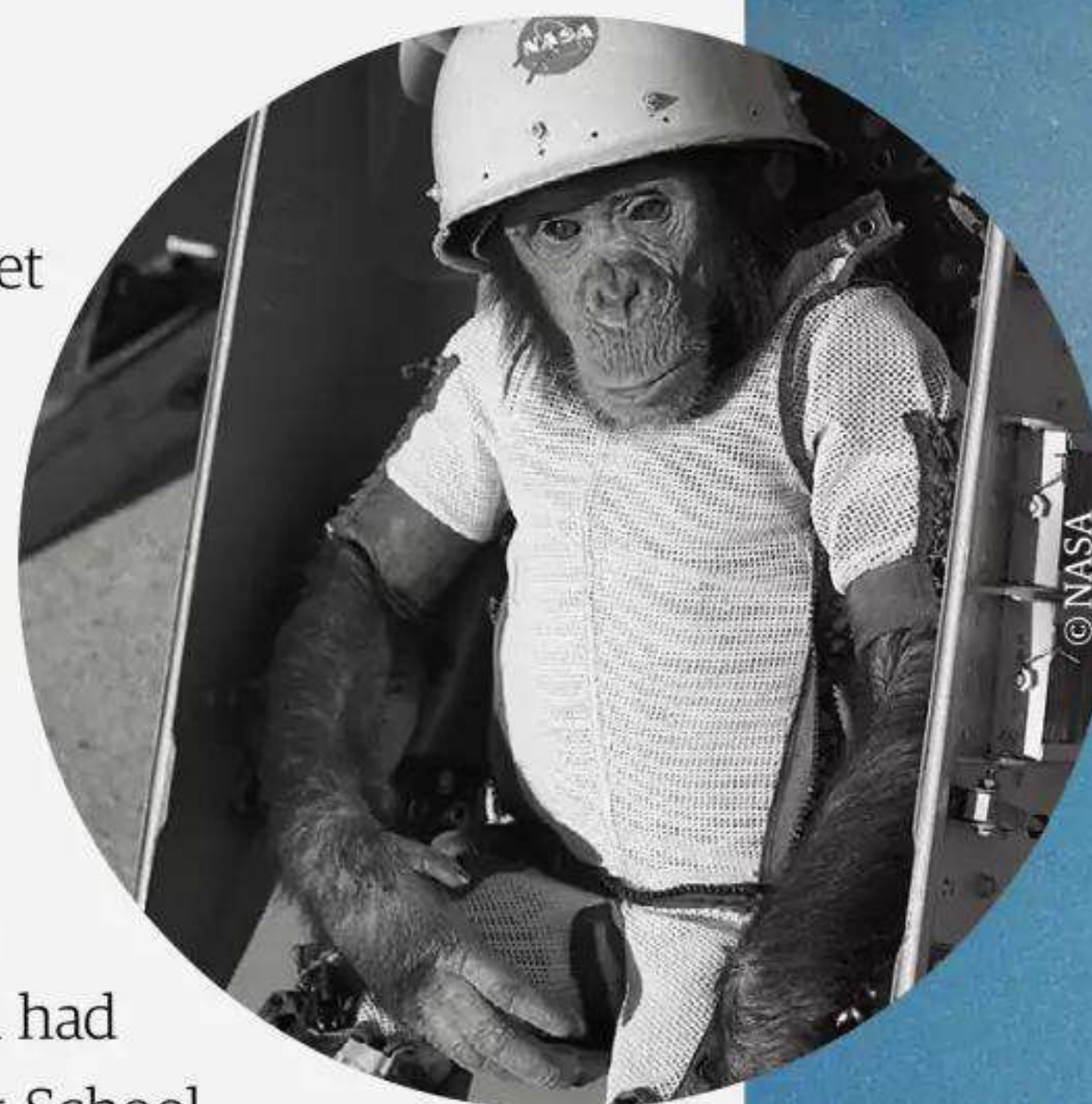
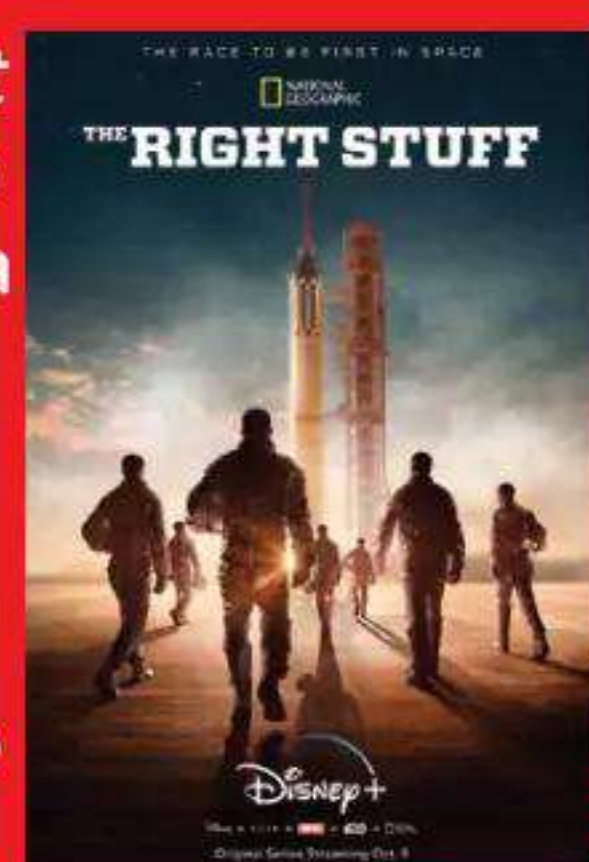
Could you pinpoint a ‘make-or-break’ moment for the Mercury program?

I don’t think there was a single make or break, but you could argue, for instance, that if either of the chimpanzee flights had failed, or had shown serious physical harm to the chimpanzees, that would have been a severe drawback to the program. It would have delayed it.

They put a chimpanzee on both a Mercury-Redstone rocket – prior to putting an astronaut in one – as well as flying one in the Mercury-Atlas, the larger launch vehicle, prior to flying John Glenn. Those were very important points in the evolution of the Mercury program.

National Geographic: *The Right Stuff*

The first episodes of *The Right Stuff* are out now and ready to watch on Disney+. It is a drama series adaptation of the book of the same name, written by Tom Wolfe. The series charts the journey of NASA’s first astronauts in their attempts to reach space.



Above: A chimpanzee called Ham rode in the Mercury-Redstone 2 capsule on 31 January 1961

Right: The Mercury-Redstone Launch Vehicle was the first crewed rocket used in the US space program

Wow! signal

WHAT'S BEHIND THE WOW! SIGNAL?

FOR OVER 40 YEARS ASTRONOMERS HAVE SOUGHT TO EXPLAIN

A MYSTERIOUS ONE-OFF 'ALIEN' SIGNAL,

BUT ARE WE NOW FINALLY CLOSE TO AN ANSWER?

REPORTED BY DAVID CROOKES



On 15 August 1977 the Big Ear radio telescope belonging to Ohio State University scanned the night sky. There was nothing unusual about this.

Turned on for the first time in 1963, the telescope had long been used to search for extraterrestrial radio signals, churning out reams of computer printouts via an IBM 1130 mainframe computer that would then be looked at in fine detail by the observatory's astronomers.

Each time someone so much as glanced at one of the jam-packed pieces of paper, they hoped to see something significant: evidence, no matter how small, that life may be out there. So when astronomer Jerry Ehman studied the data taken from that warm summer's night a few days later, he was startled. Staring at him in a vertical line was the baffling sequence of numbers and letters '6EQUJ5'. 'Wow!' he wrote, highlighting the sequence with a circle of red ink.

Since the discovery was made, there has been much debate over the source of the signal. We know for certain that it was detected as it passed across the telescope's field of view at 22:16 EST that night, and we know it was coming from a grouping of stars called Chi Sagittarii. We understand that it lasted for 72 seconds - and that it has never been detected since, not even in the weeks following the original discovery.

Perhaps most crucially, the frequency of this one-off signal was also very close to what is known as the 21-centimetre line, or hydrogen line. This is important because back in the 1960s and 1970s, it had been hypothesised that extraterrestrials looking to communicate would most likely use the most abundant element in the universe: hydrogen. This emits a radio frequency of 1,420MHz, which is exactly what was picked up by Big Ear.

"When this signal was detected at 1,420MHz, which indicated hydrogen being present in a part of the sky that had always been known to be quiet, it was like, 'oh my god! It must be aliens,'" says Antonio Paris, a professor at St Petersburg College in Florida. It explains why the 'Wow! signal', as it quickly became known, has long been associated with the possibility that it was sent by extraterrestrial life. That it was discovered in the same year as the Hollywood releases of *Close Encounters of the Third Kind* and *Star Wars* was simply a delicious coincidence.

By the mid-1980s astronomers were coming to the conclusion that it was most likely caused by a natural phenomena that had simply been undetectable. "But by then it had already become part of folklore and legend, and it had become hijacked by the science-fiction community, which has shaped it as evidence of life," Paris tells us. This, he says, had made life a little more difficult for astronomers looking to get to the bottom of what may have happened. "I started to explore the Wow!

"I STARTED TO EXPLORE THE WOW! SIGNAL SEVEN YEARS AGO, AND MY FINDINGS ARE HURTING THE FEELINGS OF A LOT OF PEOPLE" ANTONIO PARIS

signal myself 11 years ago, and my findings are hurting the feelings of a lot of people," he says.

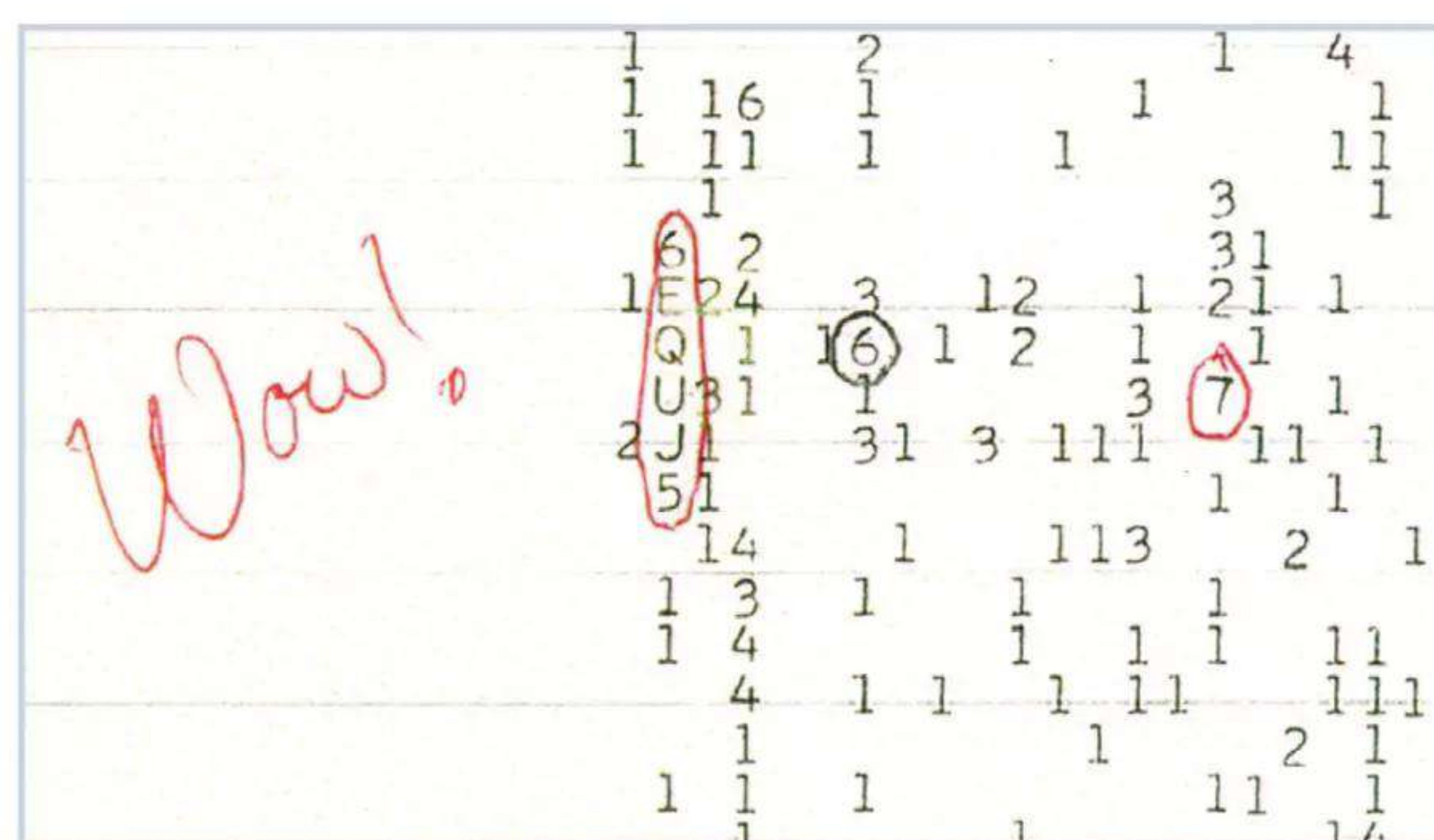
And indeed they are. In January 2016 Paris hit the headlines when he claimed the signal may have been caused by a passing comet that astronomers had yet to spot and catalogue. He pinpointed two potentials: 266P/Christensen, which was discovered in 2006, and 335P/Gibbs, which was spotted a couple of years later. These, he said, were moving through Chi Sagittarii on that memorable day in August 43 years ago. To test whether they were giving off signals that could match Wow!, Paris vowed to point a telescope at them when they passed Earth in January 2017.

Since his theory relies on comets releasing a lot of hydrogen when they orbit around the Sun - a cloud of gas being emitted when the frozen water is broken up by ultraviolet light - he hoped to be able to pick up a 1,420MHz signal in the spot where the Wow! signal was detected by Big Ear. Like the original telescope, he focused on a certain spot in the night sky. "We pointed a ten-metre telescope at 266P/Christensen on various occasions and the response was 1,420MHz, which is what we have reported," says Paris, who published a paper in the *Journal of the Washington Academy of Sciences* detailing just that in June 2017.

Almost immediately, other astronomers sought to dismiss the findings. Dr Seth Shostak, a senior astronomer at the SETI Institute, which leads the way in the search for extraterrestrial life, claimed the comet hypothesis does not work. Much rests on the fact that a single 72-second signal is all that was ever detected in 1977.

"There are many reasons, but one that I personally think is strong is to consider that the

Below: This sequence of letters and numbers shows the successive intensities of the detected signal



Wow! signal

Ohio State University Radio Observatory had two feed horns - essentially two receivers," Shostak tells **All About Space**. "It would observe whatever it was pointed at twice, separated by 70 seconds. The Wow! signal was found the first time, but it was not seen the second time. I worked the numbers, and unsurprisingly there was no way that the comet could have moved across the sky far enough to be out of the field of view of the second feed in just over a minute."

Paris sticks by his findings, claiming he always knew they would be attacked. "Before we hit that send button on our paper, I told my staff to be ready for lots of criticism," he says. He vows to repeat the experiment, but do it slightly differently next time. Rather than employing drift scanning, which meant their ten-metre telescope in Florida remained fixed while the object moved, "our next experiment will have the telescope move at the same speed as the comet so we will get a continuous signal, and that will answer a lot of questions".

Someone who is sure to be interested in the answers is Chris Lintott, professor of astrophysics at Oxford University. Like all astronomers, he is aware that there have been numerous failed attempts to redetect the Wow! signal, and that any claim to suddenly find an answer will always be greeted with scepticism. So far devices much more sensitive than Big Ear have only ever picked up faint sources of radio emissions that are certainly nothing of the intensity of Wow!. What, then, does Lintott make of the claim that comets are potentially to blame?

"Using drift scanning, the object should have traversed the field of view in about five minutes, but the signals he sees last for about 45 seconds

so they're not coming from an object traversing the main beam," he tells us. "There is also a claim of neutral hydrogen around the comet at the 21-centimetre line, and I don't believe that detection is really of the comet he is pointing the telescope at. If comets were as bright as he claims in the 21-centimetre line, they'd be picked up by large surveys of the sky that have been done for many decades. But we just don't see them."

Still, Paris, a former analyst of the US Department of Defense, insists he has covered as many bases as possible. He initially approached the Wow! signal as if he was revisiting a crime scene, looking closely at astronomical databases for clues as to what could have caused the signal. "We have tried to debunk

the theory as much as possible," he tells us, having attempted to eliminate lines of enquiry.

He has also split his investigations into three parts. "The first was the hypothesis, the second was finding the culprit, which we think is comets now, and the third is to look at how it is possible that these comets are not doing what they are supposed to be doing." In other words he will seek to discover why astronomers have never detected hydrogen emission from comets before. His research since has been focused on how it is possible that 1,420MHz can be detected from a comet - if this is common, it could help his comet theory.

It's something Alan Fitzsimmons, an astronomer at Queen's University Belfast, would no doubt like to

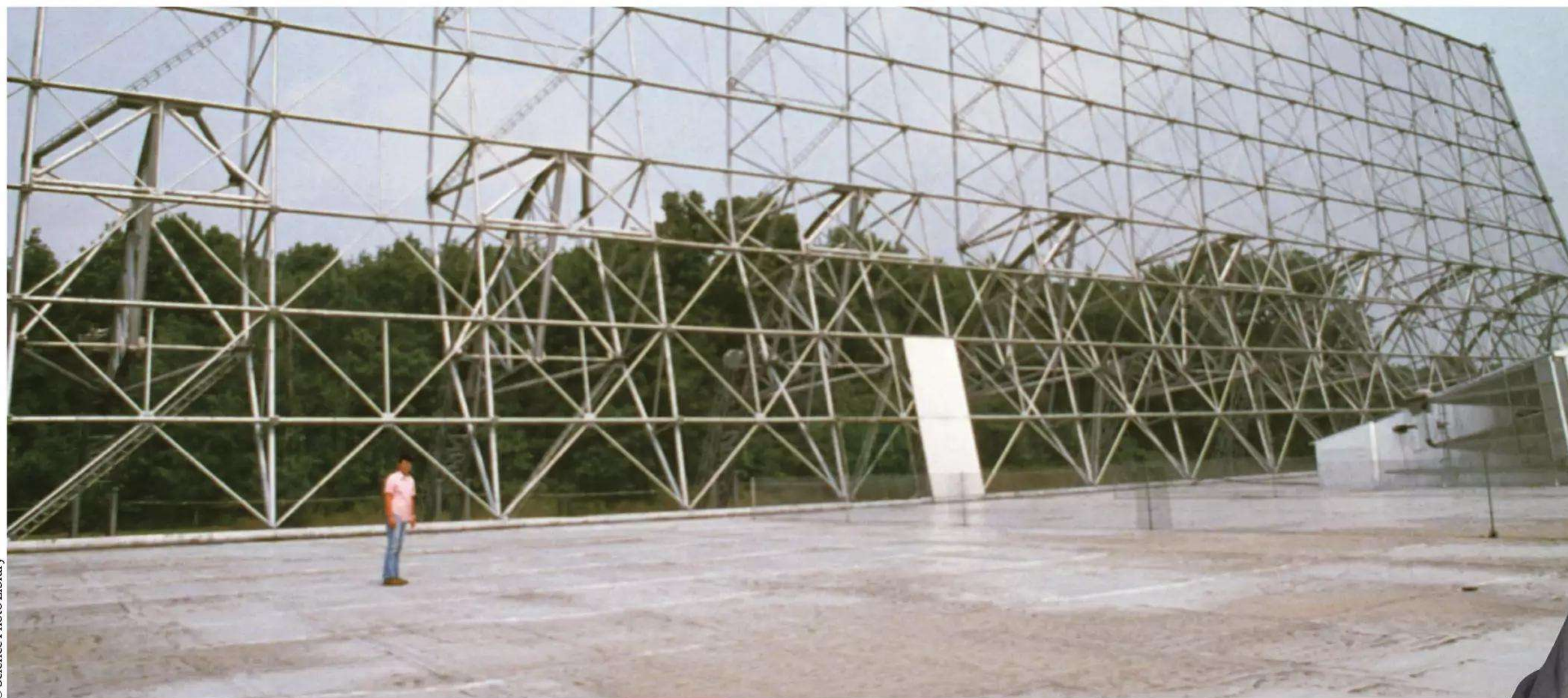
"BEFORE WE HIT THAT SEND BUTTON ON OUR PAPER, I TOLD MY STAFF TO BE READY FOR LOTS OF CRITICISM" ANTONIO PARIS

Right:
This image shows the approximate location of the Wow! signal

Below:
The North American Astrophysical Observatory's Big Ear radio telescope, which detected the Wow! signal on 15 August 1977



Source: Wikipedia Commons © Haktarfone

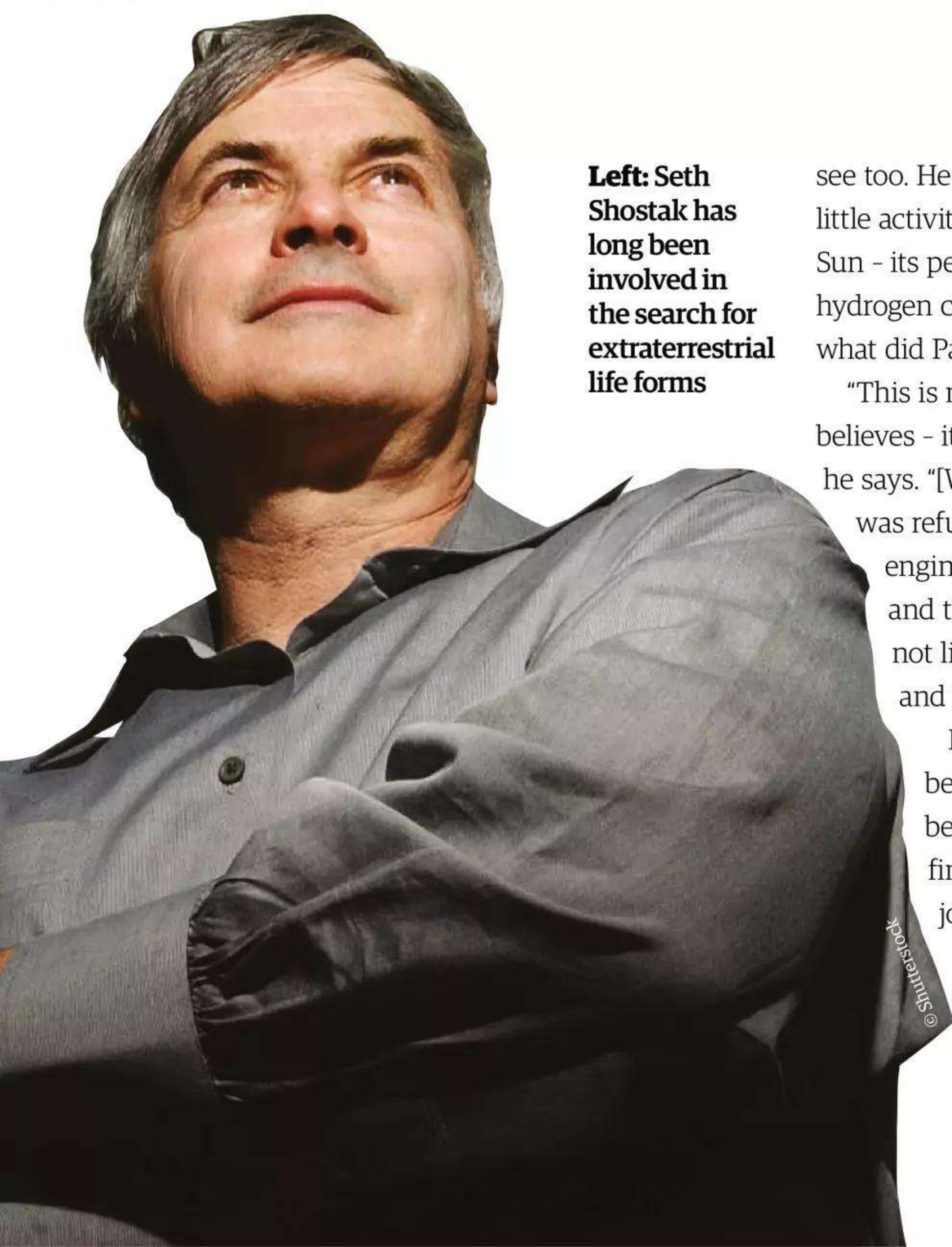
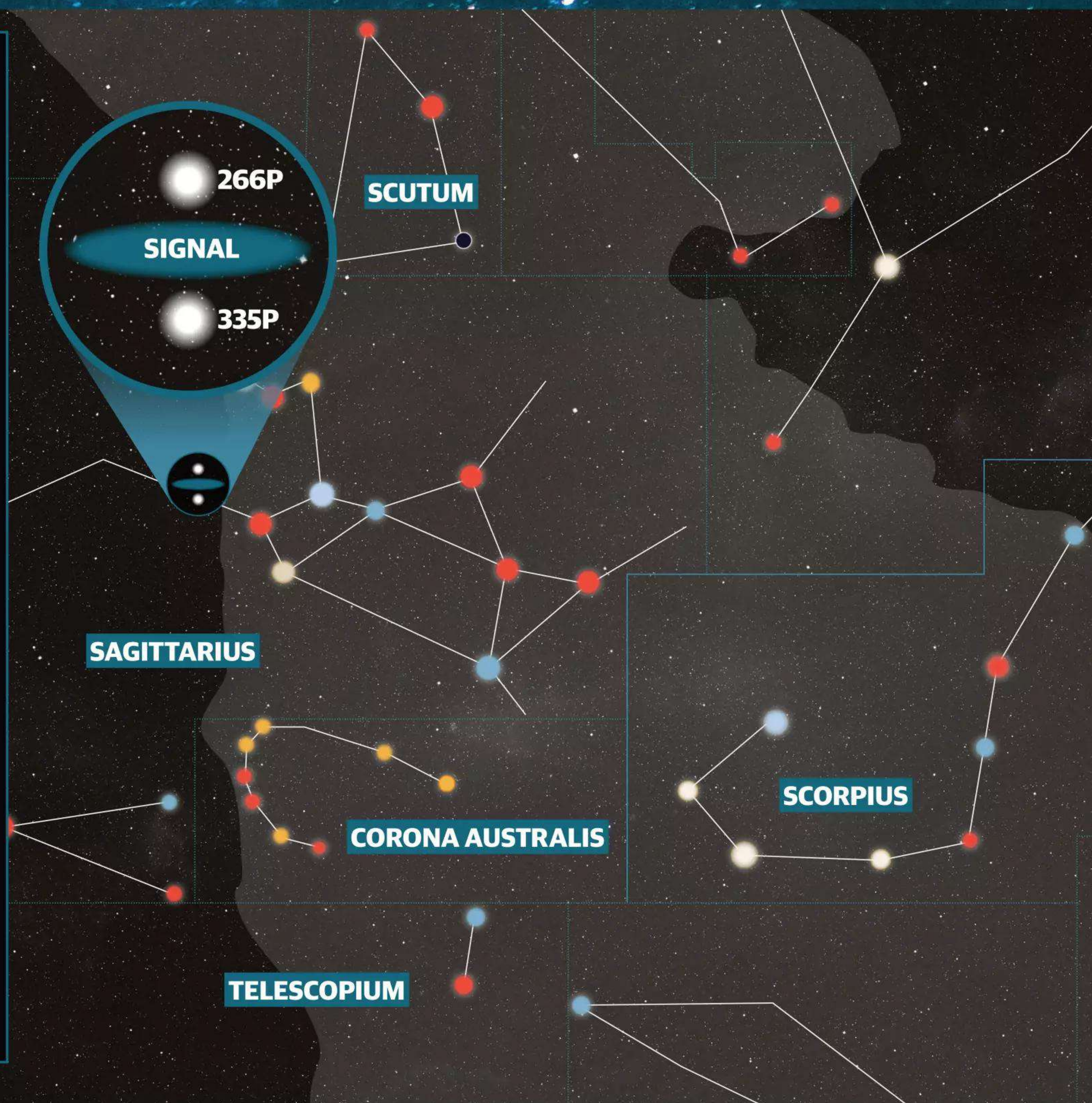


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SPECTRAL CLASS

The temperature of the stars

-  **O** Blue stars
Over 30,000 Kelvin
-  **B** Blue-white stars
10,000 to 30,000K
-  **A** White stars
7,500 to 10,000K
-  **F** Yellow-white stars
6,000 to 7,500K
-  **G** Yellow stars
5,200 to 6,000K
-  **K** Orange stars
3,700 to 5,200K
-  **M** Red stars
2,400 to 3,700K
-  **OTHER** Cool red and brown dwarfs
-  **UNKNOWN SPECTRAL CLASS**



Left: Seth Shostak has long been involved in the search for extraterrestrial life forms

see too. He has said that 266P/Christensen displays little activity when it is at its closest point to the Sun - its perihelion. "There would have been no hydrogen coma to detect," he is quoted as saying. So what did Paris see?

"This is not about what Paris saw or what Paris believes - it is what the telescope was telling us," he says. "[We used] an old NASA telescope that was refurbished with thousands of dollars. The engineers who built it for us are professionals, and they are standing by those results too. It's not like something we pulled out of our butts and wrote a paper [about]."

Even so, many astronomers remain to be convinced, and there are also questions being asked of the journal in which the findings appeared. "I'd say there are journals, and there are journals, and what I know about this journal is that it doesn't publish much astronomy," says Lintott. "My guess is that this

wasn't reviewed by an expert in radio astronomy or comets, and the reaction of astronomers when they have seen it online has been pretty negative. If Paris submitted this work to one of the mainstream journals, then the community would have given good feedback and we'd have helped him develop a better experiment."

Again Paris is able to explain and defend. "It was peer-reviewed," he insists. "The journal is well-respected with Nobel Prize winners. The objection is that an astronomy paper did not go through the usual channels, but I did that for a reason. The American Astronomical Society, of which I'm a member, is limited in scope: there are fewer than 8,000 members. If I put a paper in the normal channels, I would expect 2,000 people would read it, and it would be barely noticed in the media. But with the power of the internet and social media I can circumvent that. I have thousands of followers on Twitter that I can reach out to and get an unbelievable response. It worked because I had

Wow! signal

30,000 downloads of this paper, which would never have happened if it was buried among others."

With that in mind, it is likely the final paper will also end up outside of the mainstream astronomical journals as Paris prepares to push ahead with his third stage of investigation. "What is important right now is how many comets can emit a 1,420MHz source: is it a handful of comets or all of them?" he asks. "And that is a new subject, looking at how these comets differ from each other. We'll have the final paper published in a few years, and it will answer some of the critics' questions."

In the meantime, explanations remain up in the air, just as they have for four decades, which means other possibilities for the signal such as gamma-ray bursts or potential radio interference remain on the table. "The Ohio State folks I talked to about this long ago figured it was just terrestrial interference," says Shostak. "The basic problem in science is that if you see a strange phenomenon only once, it's hard to say much about it. It could be many things, but it's not legitimate to call it an alien signal."

Although that would disappoint some - "everyone wants it to be an alien. Of course you want it to be an alien," laughs Lintott - Paris' experiments may at the very least eliminate one theory. "In some sense he has carried out a good experiment," Lintott tells us. "You could think of every other possible explanation for the signal and test them too."

Right: Could a comet really be the source of the signal which has baffled astronomers for so long?

Below: SETI has been in effect for decades, with no confirmation of an alien signal yet

What, though, if Paris is right? "It would change our understanding of comets," says Lintott. And if he is wrong? He is already receiving hate mail about his paper. "They are from the UFO community, and I can't respond to those," says Paris. Will he regret even exploring this phenomena? "No," he counters, promising that he would be more than happy to throw up his arms and admit to being wrong if that was indeed the case. "There's nothing wrong about being wrong. I'm not getting emotional about it," he says. Instead he'd be more than pleased that his investigations have made an impact.

"The theory has been getting criticism, but I think that is the whole purpose of any science," he

explains. "To spark questions that eventually lead to more science. But I think we are at the point where there has been a lot of discussion about whether the comet could be the culprit or not, so the intention of the paper has been a success. It has opened the door to a mystery that has been dormant for a long time." Whether it stays that way remains to be seen.



David Crookes

Science & technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.



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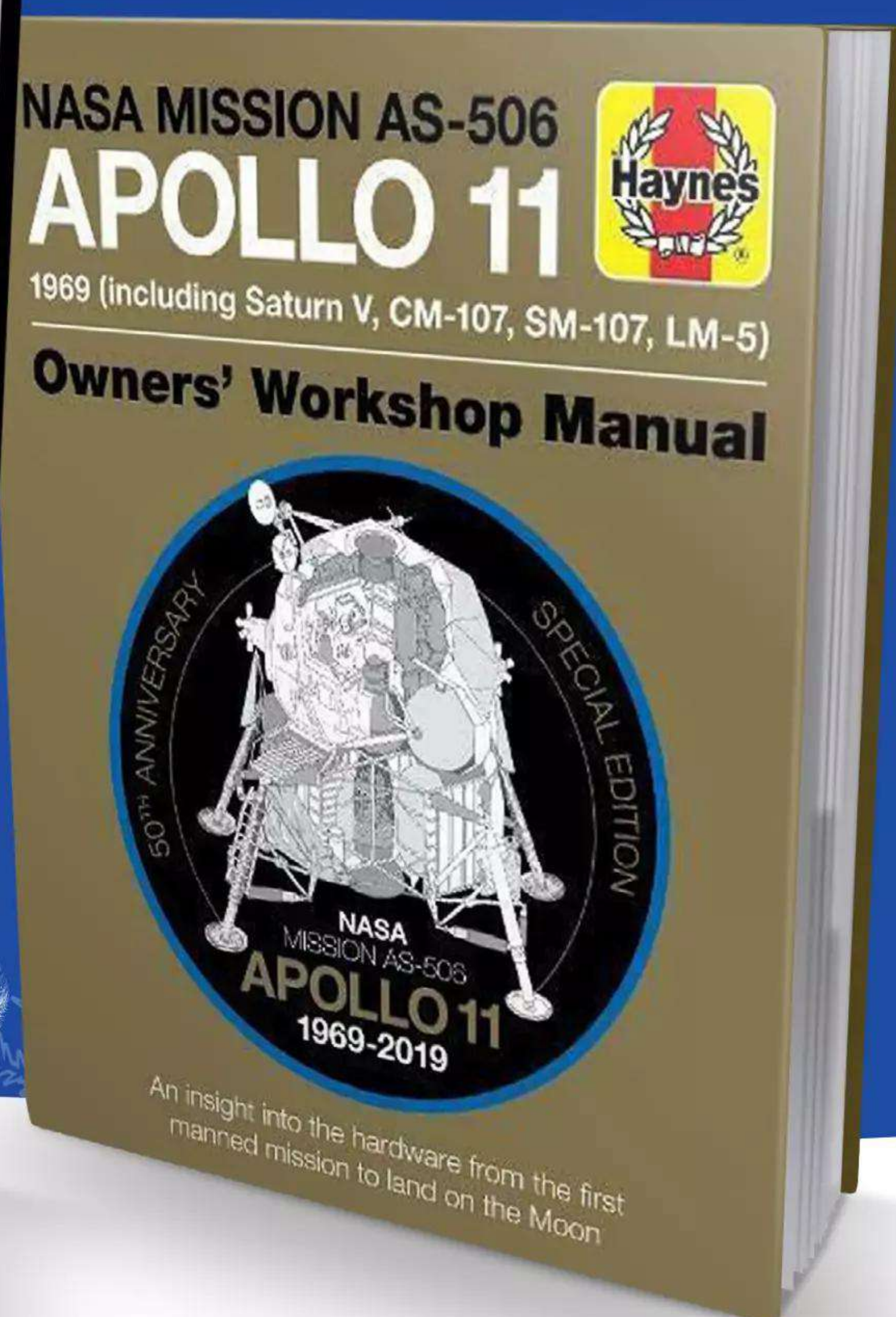
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Supergiant galaxies

SUPERGIANT GALAXIES

CLASSSED AS SOME OF THE MOST
MASSIVE OBJECTS IN THE UNIVERSE,
THESE COSMIC BEHEMOTHS ARE
ALSO THE MOST MYSTERIOUS

Reported by Giles Sparrow

Our galaxy, the Milky Way, is big. With a diameter of 100,000 light years, this enormous disc of stars is large for a spiral galaxy. But imagine a galaxy extending to almost 20 times the diameter of the one we call home – so big that if it were to replace our Milky Way, it would not only engulf nearby satellite galaxies such as the Magellanic Clouds, but its outer limits would reach nearly all the way to Andromeda, about 2.5 million light years away.

That's the staggering scale of IC 1101, an enormous ball of stars more than a billion light years away that is one of the largest measured galaxies in the known universe. It's an extreme example of a supermassive 'cD' galaxy – a class of objects very different from the Milky Way. cD galaxies are closely related to smaller elliptical galaxies – balls of old red and yellow stars that vary in size – from tiny dwarfs to giants with the diameter of the Milky Way – and differ in shape – from perfect spheres to elongated cigars. But they also differ in some other important ways.

"cD galaxies have an extra-large extended and diffuse luminous envelope of stars," explains Dr Alessia Longobardi of Aix-Marseille University, France. "They are among the most luminous and massive galaxies in the universe. For example, recent studies of Messier 87 (M87), the cD galaxy at the centre of the nearby Virgo Cluster, attribute to this galaxy a total of around 1,014 solar masses. That's roughly 100 times more massive than our own galaxy, the Milky Way."

The term 'cD' comes from the Yerkes galaxy classification scheme used by many specialist astronomers. The letters don't officially stand for anything, but astronomers have come up with a variety of 'backronyms'. They are sometimes referred to as 'cluster dominant', 'central dominant' or 'central diffuse'. As those names imply, cD galaxies have a very specific distribution in space that offers an important clue to their origins. While spirals, smaller ellipticals and irregular galaxies are scattered widely across space, cD galaxies are found only in massive, dense clusters – regions containing tens or even hundreds of substantial galaxies crammed into a volume of space a few million light years across. What's more, they tend to lie close to the very centre of these clusters. In such closely packed environments collisions between galaxies are common, and it's this process that's thought to give rise to monster galaxies.

"The most popular scenario to describe the formation and evolution of galaxies is the hierarchical paradigm," says Longobardi. "Structures form in a bottom-up, hierarchical manner by which smaller fragments that have been attracted gravitationally merge together to form more massive systems. A major merger occurs when the masses of the merging galaxies are comparable.

Right: Workers study Hubble's main 2.4-metre (eight-foot) mirror, which has revealed unprecedented details in distant galaxies

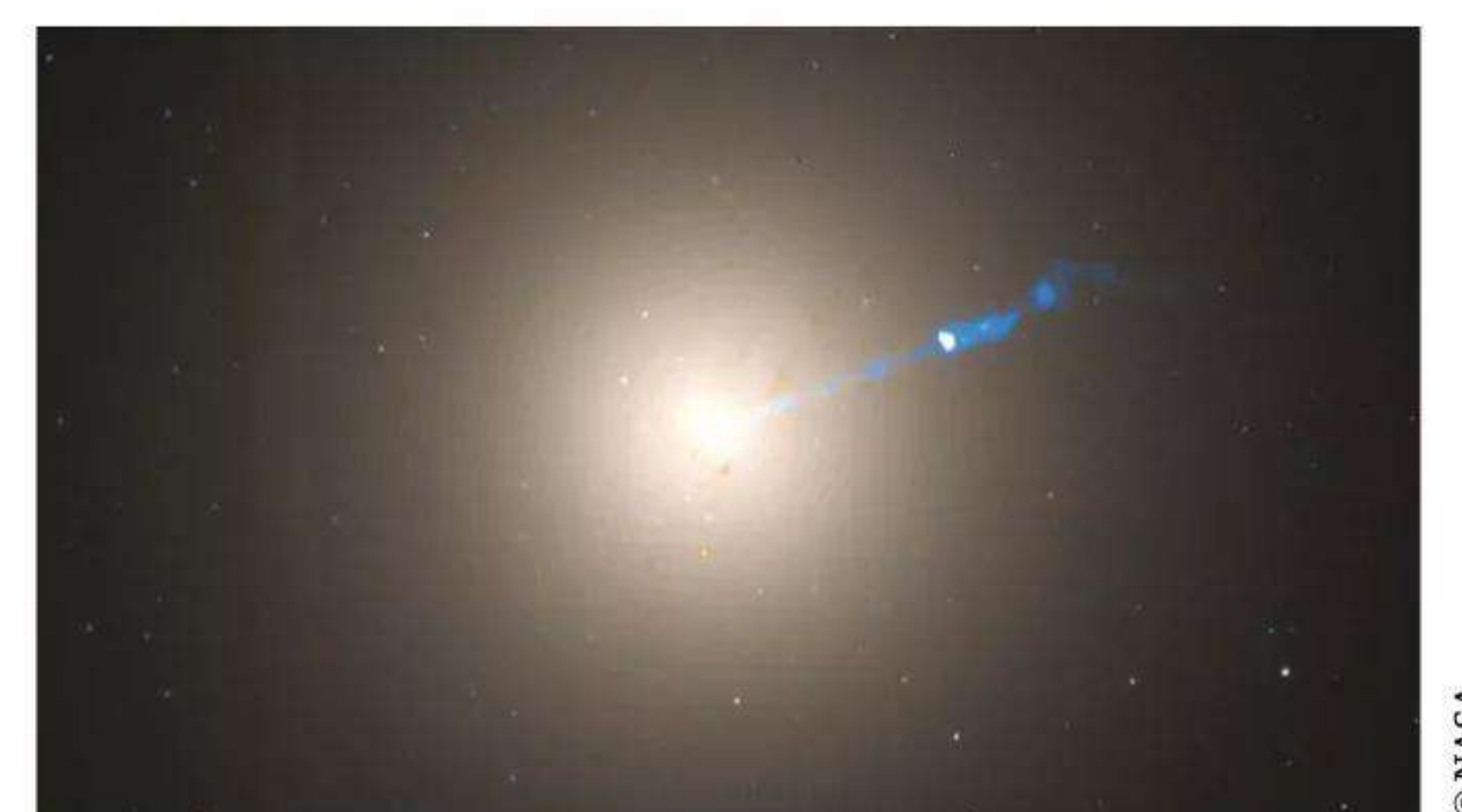
Below: M87 shows the typical yellowish hue caused by the dominance of older, lower mass stars in elliptical galaxies



"M87 HAS COLLIDED WITH A MID-SIZED GALAXY WITHIN THE PAST BILLION YEARS, AND IT IS STILL IN THE PROCESS OF ABSORBING ITS STARS AND OTHER MATERIAL"

"It results in a remnant with properties significantly different from either progenitor. Such major mergers are thought to be responsible for the formation of ball-shaped galaxies from pre-existing disc-like galaxies," Longobardi continues. "Fast changes in the gravitational forces acting across the system can turn the ordered orbits seen in discs into the random motions observed in ball-shaped galaxies. And simulations show that the most massive systems, like cD galaxies, are going to experience mergers up to five times in their dynamical evolution history."

But the direct effect on the orbits of stars is just one consequence of these intergalactic collisions. Just as important is their influence on a galaxy's nebulae – the interstellar gas clouds that provide the raw material for new star formation. Such clouds are plentiful in disc-shaped spiral galaxies, but are largely absent in all types of elliptical galaxy.



Astronomers think they are driven off during major mergers. While stars, as relatively small objects, tend to pass by each other before being affected by gravity, collisions between the more diffuse nebulae will create enormous shock waves.

In the short term, this massively boosts the rate of star formation in an effect called a starburst, but in the longer term the heating effect of the shock wave gives individual atoms and molecules the speed they need to escape from the gravitational attraction of the galaxy's stars and other matter. As a result, gas bleeds away into a halo region around the galaxy, where it is only loosely bound by the galaxy's gravity and is too fast-moving and sparse to create new stars. This is why elliptical galaxies tend to be dominated by comparatively faint, old red and yellow stars. The laws of stellar energy generation mean that heavier stars shine brighter and hotter, but also burn through their supplies of fuel much more quickly, ageing and dying while lower mass, cooler stars keep steadily ticking over. Within a few hundred million years of the original collision, all the galaxy's brighter stars will have reached the end of their lives – and with no ongoing star-formation process, the more sedate red and yellow stars will become dominant.

HOW BIG GALAXIES ARE MADE

Giant galaxies and other massive ellipticals go through a series of changes on their way to becoming the monsters of the present-day universe

1 Big Bang

Around 13.8 billion years ago

The universe began in a vast explosion that gave rise to space, time and all matter. The Big Bang left behind large-scale differences in the distribution of both normal 'luminous' matter and the far more plentiful invisible 'dark' matter. Dense patches of matter formed the nuclei around which the first stars and galaxies began to coalesce.

2 Merger

Around 12 billion years ago

The first galaxies to form were gas-rich systems full of young, massive and short-lived stars. Collisions and mergers between these small galaxies were frequent, and large galaxies began to develop disc-like structures with spiral arms. When these in turn collided, the results were the first elliptical galaxies.

3 Starburst galaxy

Around 11 billion years ago

Close encounters, collisions and mergers raised tidal forces and created tremendous shock waves, both of which accelerated the rate at which clouds of gas and dust condensed to form stars. The absence of heavier elements allowed these early stars to grow much more massive and luminous while remaining stable.

4 Quasar

Around 10 billion years ago

Supermassive black holes in the centres of these galaxies began life as collapsing gas clouds. As they drew in more material, they swelled in size and developed into active galactic nuclei (AGN) – discs of superheated infalling matter that generate intense radiation. Quasars, star-like points of brilliant light embedded in the cores of distant, young galaxies, are the best known among several types of AGN.

5 Compact galaxy

Around 8 billion years ago

As spirals and irregular galaxies continued to collide and merge, the gas within them grew hotter and sparser, eventually detaching itself from individual galaxies and spreading out into the surrounding cluster. Mergers in galaxy clusters began to produce galaxies that resembled spiral hubs without the raw material to generate new generations of stars.

“cD GALAXIES, LIKE M87, GROW THROUGH A PROCESS OF COSMIC CANNIBALISM”

6 Merging galaxies

Around 5 billion years ago

As the universe matured, mergers between galaxies continued within dense galaxy clusters, where local gravity could dominate over the general expansion of the universe dragging galaxies apart. With each fresh merger, the larger elliptical galaxies grew heavier and more influential on their neighbours. Many developed extensive outer halos dominated by captured stars.

7 Giant elliptical galaxy

Today

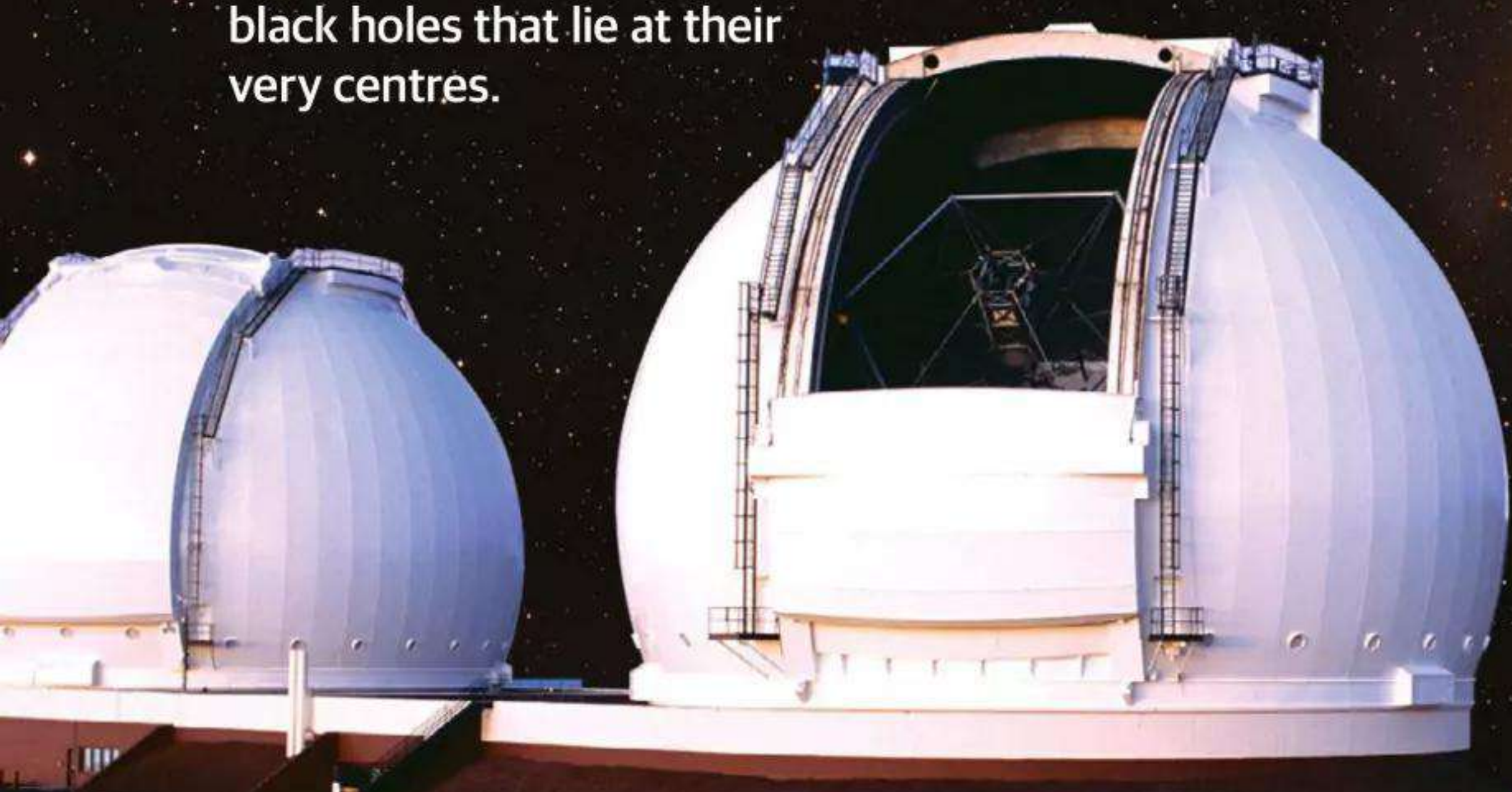
The largest present-day cD galaxies have stellar halos that are millions of light years across, with thousands of globular clusters formed in earlier mergers and central black holes with a mass equivalent to billions of Suns. In the future they will grow even larger.

W. M. Keck Observatory

First light: 1993

Notable achievements: First observatory to combine the light of two giant telescopes for sharper images

Astronomers have used the Keck telescope to measure the motion of stars in the compact cores of giant ellipticals, helping to confirm the enormous mass of the black holes that lie at their very centres.



Hubble Space Telescope

Launch date: 1990

Operator: NASA/ESA

Notable achievements:

First large visible-light telescope in orbit

Hubble's uniquely sharp vision has revealed unprecedented details in distant giant galaxies, helping to trace their extensive halos and the presence of globular clusters in orbit around them.

Herschel Space Observatory (defunct)

Launch date: 2009

Operator: ESA/NASA

Notable achievements:

Infrared observatory for observing the cool universe of the far-infrared

In 2014 Herschel showed that some giant ellipticals do still contain cold star-forming gas, and also showed that star birth is prevented by the influence of jets from the central black hole in M.

Spitzer Space Telescope (defunct)

Launch date: 2003

Operator: NASA

Notable achievements:

Near- and mid-infrared telescope designed to work in collaboration with Hubble

Spitzer's infrared abilities helped it reveal compact ellipticals forming when the universe was still young, showing how the seeds of cD galaxies were sown.

The closest cD galaxy to Earth is M87, which lies at the centre of the Virgo Cluster, the nearest dense galaxy cluster to us at a distance of roughly 54 million light years. M87 is a ball of stars with roughly the same diameter as the Milky Way, and is surrounded by a sparse stellar halo that extends across about a million light years. Thanks to its proximity, it's the most closely studied of this class of galaxy, and astronomers have discovered some interesting features that are probably shared by most other giant ellipticals.

"M87 has one of the oldest stellar populations in the local universe and has an extended stellar halo that produces 70 per cent of the galaxy's total light," explains Longobardi. "The motion of its component galaxies suggests that the Virgo Cluster is still in the process of forming, and photometric studies have revealed a complex network of faint, extended tidal features around M87, suggesting that it is not completely in equilibrium." One piece of evidence for M87's long history of past mergers is the huge halo of globular star clusters that surrounds it. These relatively small but densely packed balls of stars are thought to be the surviving fossils of brilliant 'super star clusters' formed during starburst events. While our Milky Way has perhaps 200 such clusters in orbit around it, M87 has a staggering 12,000.

"M87 is a prime target to test galaxy formation and evolution theories," explains Longobardi. "Cosmological simulations suggest a two-phase scenario for the formation of massive spheroids like cD galaxies. The first phase happens earlier in the history of the universe and leads to the formation of a compact progenitor to the present-day elliptical.

Later on the system sweeps up, or 'accretes', many more stars through mergers, which increase its size with time. These accreted stars preferentially make up the stellar halo component and dominate the outer regions of the galaxy."

M87 is a particularly good target not just because of its proximity to Earth, but also because its location coincides with the Virgo Cluster's overall centre of mass. As a result galaxies are more strongly drawn towards it by gravity, and the various types of merger and interaction are both more frequent and more dramatic. Because of this, Longobardi and her team were able to use a unique approach to find evidence of an accretion event in M87's fairly recent history.

"According to the hierarchical framework, the outer regions of a galaxy contain an enormous wealth of information," enthuses Longobardi. "The time needed to 're-mix' accreted stars in this region is much longer, so they can preserve fossil records of past merger events in the form of long-lasting substructures." The challenge, however, is that individual regions within galaxy halos are very hard to study thanks to their low brightness. After all, M87 might be nearby compared to other cD galaxies, but it's still tens of millions of light years away. The researchers overcame this challenge by looking for one very specific type of object called a planetary nebula - an expanding bubble of material flung off into space during the death throes of Sun-like stars.

"When we observe planetary nebulae we are seeing the glowing shells around ageing stars," says Longobardi. "These objects shine very brightly in a specific hue of aquamarine green, so they can be

Right:
The Flight
Operations
Team at
NASA's
Goddard Space
Flight Center,
Maryland,
monitor
Hubble
constantly



“IN SUCH CLOSELY PACKED ENVIRONMENTS COLLISIONS BETWEEN GALAXIES ARE COMMON, AND IT’S THIS PROCESS THAT IS THOUGHT TO GIVE RISE TO MONSTER GALAXIES”

distinguished from the surrounding stars and easily detected out to the extreme extension of a galaxy.” Planetary nebulae can reveal more than just the distribution of stars in the galaxy’s outer halo. By studying individual nebulae with a spectrograph, it’s possible to work out whether these objects are moving towards or away from us, and at what speed they are travelling. “Through studying these motions – peculiar with respect to the rest of the halo stars – I was able to identify the new accretion event. I also looked at the light distribution and I found evidence of extra light coming from the stars of a ‘swallowed’ satellite galaxy.”

The discovery suggests that despite its outwardly uniform appearance, M87 has collided with a mid-sized galaxy within the past billion years, and is still in the process of absorbing its stars and other material. “Thanks to the enormous gravitational tidal forces involved, stars are now scattered over a region that is 100-times larger than the original

galaxy,” concludes Longobardi. “It shows directly that large, luminous structures in the universe, like M87, are still growing in a substantial way through the accretion of smaller systems, as predicted by hierarchical galaxy evolution models.” This discovery seems to be clinching proof that cD galaxies grow through a process of cosmic cannibalism, but it also raises intriguing questions about the fate of the absorbed galaxy’s other components. The answer may lie in the central regions of the galaxy, thought to be home to black holes with unimaginable mass.

The black hole at the heart of M87, for example, is one of the largest discovered so far, with an estimated mass of 6.5 billion Suns. M87’s black hole is also the origin of a powerful jet of particles that shoots out across 5,000 light years of space. As tidal forces shred and heat up material falling towards the monster’s gravitational maw, it forms a superheated ‘accretion disc’. Powerful magnetic fields, meanwhile, allow some particles to escape in narrow beams from above and below the disc, creating an overall structure called an active galactic nucleus (AGN).

Until recently M87’s AGN had been something of a mystery – after an initial period of violent activity, most supermassive black holes seem to clear out objects from their immediate surroundings, becoming dormant and hard to detect. M87’s activity is likely caused by new infalls of material, triggered during the recent galaxy merger, which have sparked the black hole back to life. Research by Dutch and American astronomers using the infrared Herschel Space Observatory, meanwhile, has shown that AGNs may have another

important effect – by heating up cold gas in their surroundings, such as that injected into a largely gas-free cD galaxy during a merger, they make it harder for new stars to coalesce, ensuring that from a star-formation point of view, the galaxy remains as dead as it was before the merger.

But there’s one final question. Assuming the enormous mass of M87’s black hole is typical for all cD galaxies, how do these objects get so big? The answer lies in a chain of events as spectacular as these giants themselves. Evidence now suggests that all substantial galaxies contain black holes at their hearts, and during a galactic merger these core regions will tend to sink towards the system’s centre of mass, eventually falling into orbit around each other. The result can be a galaxy with two distinct and bright nuclei, but this may not be sustainable in the long term – if some mechanism exists to reduce the momentum of the two black holes, then their separation will steadily reduce and they will spiral in towards each other on a collision course.

Eventually the black holes will collide and merge into a single super-dense object whose enhanced gravity may draw in more material from its surroundings, allowing it to grow ever stronger and more massive. Therefore, over several repeated mergers, the biggest galaxies in the universe develop even more monstrous black holes at their hearts, and so the cycle continues.



Giles Sparrow
Space science writer

The author of over 20 books on popular science, Giles holds a degree in astronomy and is an editor specialising in science and technology.



Above: Giant elliptical galaxies form the gravitational anchors around which cluster galaxies move – as seen in the Virgo Cluster around Messier 87

Left: The Antennae Galaxies are a pair of colliding spirals undergoing an intense starburst. Eventually they’ll coalesce into an elliptical ball



SIZING UP GALAXIES

Most of the largest structures are elliptical, but there are some notable exceptions

1 Milky Way

Size of galaxy: 100,000 light years

Type of galaxy: Barred spiral

2 Messier 87

Distance: 54 million light years

Size of galaxy: 120,000 light years

Type of galaxy: Elliptical

The closest giant elliptical to us has a monster black hole at its heart and an active galactic nucleus thanks to a recent merger. However, its extended outer halo of stars seems to have been truncated by the influence of other nearby galaxies.

3 UGC 1382

Distance: 250 million light years

Size of galaxy: 718,000 light years

Type of galaxy: Spiral

Astronomers discovered this rare 'Frankenstein galaxy' in the constellation of Cetus. Originally assumed to be an ancient elliptical, ultraviolet and radio images revealed the presence of tenuous spiral arms and huge gas clouds, probably cannibalised from other galaxies.

4 NGC 1275

Distance: 237 million light years

Size of galaxy: 100,000 light years

Type of galaxy: Elliptical

The central cD galaxy of the Perseus Cluster, NGC 1275 has an active galactic nucleus and is also known as the radio source Perseus A. Seen from Earth, another dusty galaxy lies directly in front of it, falling towards the cD galaxy on a collision course.

5 IC 1101

Distance: 1.04 billion light years

Size of galaxy: 4 million light years

Type of galaxy: Elliptical or lenticular

IC 1101 is often described as the largest known galaxy in the universe. Its extended outer halo of stars suggests it is a cD galaxy, but some astronomers suspect the halo is actually a face-on disc, making it a lenticular instead.

6 NGC 1399

Distance: 66 million light years

Size of galaxy: 130,000 light years

Type of galaxy: Elliptical

Like Messier 87, NGC 1399, the central galaxy of the nearby Fornax Cluster, is surrounded by a large number of globular clusters – around 6,000 – revealing a long and ancient history of galactic mergers and starbursts.

7 NGC 4889

Distance: 308 million light years

Size of galaxy: 250,000 light years

Type of galaxy: Elliptical

One of two supergiant elliptical galaxies that anchor the Coma Cluster, NGC 4889 is home to a central black hole that contains a staggering 21 billion solar masses of material.

8 NGC 5128

Distance: 13 million light years

Size of galaxy: 80,000 light years

Type of galaxy: Elliptical/lenticular

This is a nearby example of a merger in action and a galaxy on its way to becoming a giant elliptical. Seen in visible light, the dust from a foreground spiral forms a dark lane across the larger lenticular galaxy.

9 NGC 6872

Distance: 212 million light years

Size of galaxy: 522,000 light years

Type of galaxy: Barred spiral

One of the biggest spiral galaxies, thanks to its elongated arms. They have probably unwound into their shape under the influence of tidal forces from a much smaller nearby lenticular galaxy, known as IC 4970.

A WEIRD WORLD AROUND A WARPED STAR

The spacecraft CHEOPS has categorised a strange new exoplanet with an odd orbit

Europe's new telescope studying alien planets has created its first detailed portrait of a world, and it's a weird one: hot and tilted around a warped star.

The European Space Agency (ESA) launched the CHAracterising ExOPlanets Satellite, nicknamed CHEOPS, in December 2019; the spacecraft began science observations in April. CHEOPS isn't designed to discover alien planets, but rather to inform scientists so that they can construct portraits of the worlds. In the mission's first results, scientists on the CHEOPS mission have done just that, forming a detailed picture of the planet WASP-189b, which was first detected in 2018. "This first result from CHEOPS is hugely exciting," Kate Isaak, project scientist for CHEOPS at the ESA, said. "It is early definitive evidence that the mission is living up to its promise in terms of precision and performance."

The CHEOPS observations suggest that WASP-189b is a strange world orbiting a strange star. Scientists had a hunch that might be the case, which is why mission scientists chose to study the planet so early in the spacecraft's tenure. The star is super-hot - so hot it looks blue - and the planet is so close to the star it orbits in just 2.7 Earth days. "Only a handful of planets are known to exist around stars this hot, and this

system is by far the brightest," Monika Lendl, an astrophysicist at the University of Geneva in Switzerland and lead scientist, said. "WASP-189b is also the brightest hot Jupiter that we can observe as it passes in front of or behind its star, making the whole system really intriguing."

Observing a planet passing in front of its star is, at this point, fairly commonplace - the so-called transit technique is how NASA's venerable Kepler Space Telescope and its successor, the Transiting Exoplanet Survey Satellite (TESS), spot planets blocking light as they pass in front of stars. Watching a planet pass behind its star is much more difficult, but WASP-189b is so bright that scientists can do just that. "Because the exoplanet WASP-189b is so close to its star, its dayside is so bright that we can even measure the 'missing' light when the planet passes behind its star," Lendl said. "It appears that the planet does not reflect a lot of starlight. Instead most of the starlight gets absorbed by the planet, heating it up and making it shine."

CHEOPS studied WASP-189b in March, April and June, catching the planet passing behind its star four times and in front of the star twice. From that data, scientists calculated some key features of the system. First the researchers determined that the planet is pretty toasty at about 3,200 degrees Celsius (5,800 degrees

Fahrenheit) - so hot that even iron would turn to gas. The scientists also calculated the planet's size: about 1.6 times the radius of Jupiter.

The new CHEOPS observations also told scientists more about WASP-189b's star. "We also saw that the star itself is interesting - it's not perfectly round, but larger and cooler at its equator than at the poles, making the poles of the star appear brighter," Lendl said. "It's spinning around so fast that it's being pulled outwards at its equator!"

Unlike in our Solar System, where planets orbit around the Sun's equator, WASP-189b orbits its star at a dramatic tilt, bringing it close to the star's poles. That odd characteristic makes scientists suspect that the planet could have formed much farther away from the star, then some powerful gravitational force - perhaps another star - kicked the planet inward and askew. The CHEOPS scientists say that this sort of work is precisely what the telescope was designed to do: take a known exoplanet and give scientists a more detailed view of the world than a passing shadow. "CHEOPS will not only deepen our understanding of exoplanets," Isaak said, "but also that of our own planet, Solar System, and the wider cosmic environment."

Below: Artist's impression of hot Jupiter WASP-189b

“ONLY A HANDFUL
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SYSTEM IS BY FAR
THE BRIGHTEST”

MONIKA LENDL

THE HUNT FOR WORMHOLES

Usually confined to the pages of science fiction, astronomers are starting to think these portals through space-time might be real after all

Reported by Colin Stuart

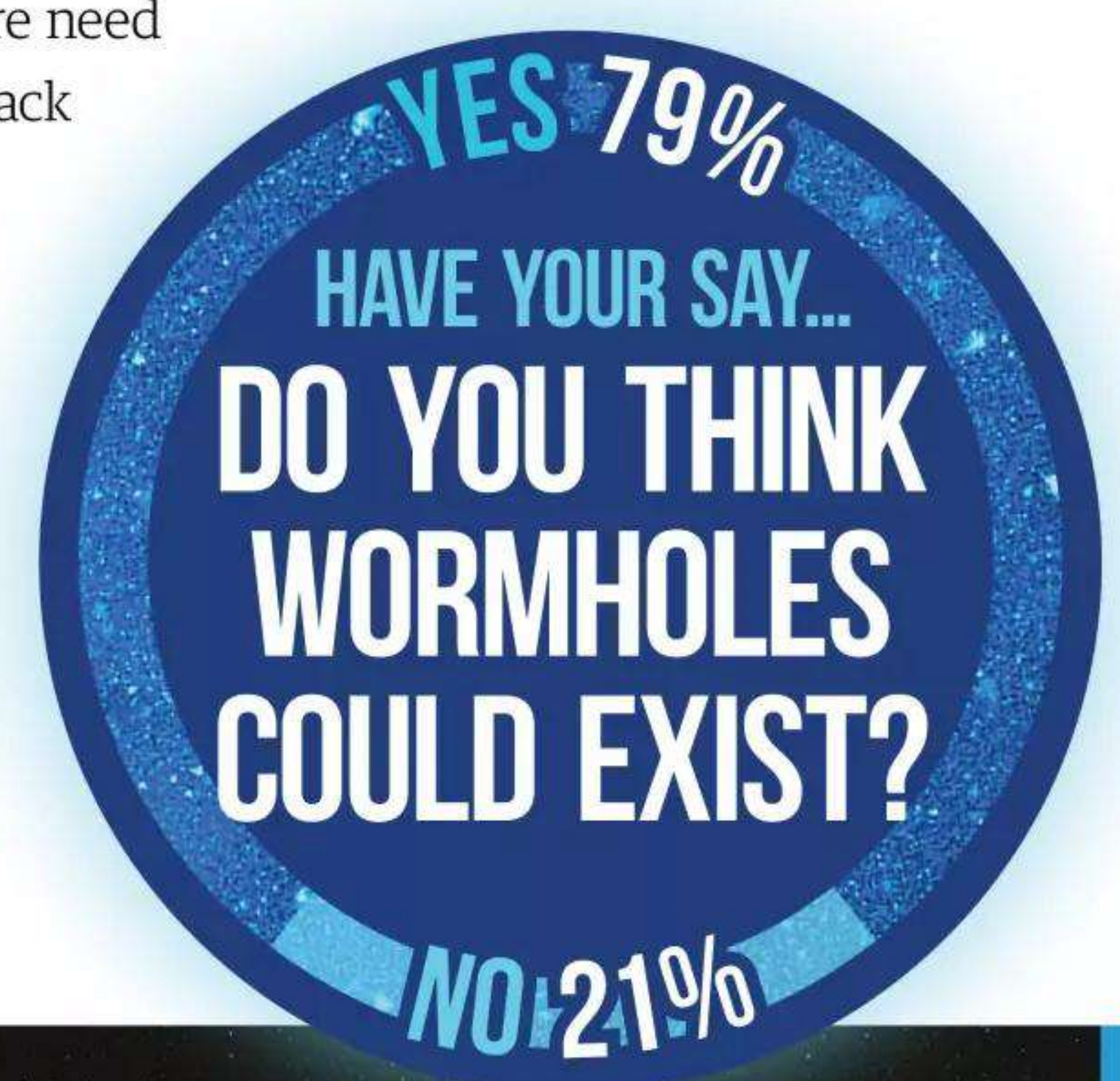
It was the plot for an epic 2014 Hollywood blockbuster. In *Interstellar*, a crew of astronauts travel across space on the hunt for an alternative home for humanity. Yet they don't leave our Solar System by the conventional route; instead they head into a wormhole in the vicinity of Saturn and emerge almost immediately in a distant galaxy. These wormholes - shortcuts in space and time - have long been a staple of science fiction.

But some scientists believe we may soon be able to prove that they are a real part of the universe - as real as the Sun and the stars or you and I. The scientific term for this exotic object is an Einstein-Rosen bridge, which is a clue as to where the idea came from. Wormholes are rooted in Albert Einstein's general theory of relativity - his groundbreaking masterpiece that turned our ideas about gravity on their head. For centuries we thought we knew how gravity worked, thanks to Isaac Newton. Apples fell to the ground and the Earth stayed in orbit around the Sun because of a gravitational pull between the objects. Yet Einstein saw it differently, suggesting that what we experience as gravity is simply a bending of space

"WITH THIS NEW SET OF RULES IT WOULD BE POSSIBLE FOR AN OBSERVER TO GO THROUGH A WORMHOLE AND CROSS OVER TO ANOTHER REGION OF THE UNIVERSE" DIEGO RUBIERA-GARCIA

and time. Under this radical new regime, the Earth orbits the Sun because our star's mass warps the space around it, much like a bowling ball would warp a bed sheet if it were placed in the centre of it. Our planet is simply following the local curvature of this fabric, which Einstein called 'space-time'.

Such a crazy idea was in dire need of experimental evidence to back it up. Crucially, a solar eclipse in 1919 offered just such an opportunity. When the Moon blocked out the Sun, it was dark enough to see stars close by. Yet we don't see these stars where they really



WHAT IS A WORMHOLE?

There's more than one type of shortcut for long journeys across and beyond the universe

Type 1: connecting our universe to itself

This is the transport mechanism used by the crew of astronauts in the film *Interstellar* as a shortcut between our Solar System and a distant galaxy. Einstein's general theory of relativity suggests it might be possible to bend space-time sufficiently to bring you and your destination much closer together.

Type 2: our universe connects to another

The equations of Einstein's general theory of relativity blow up in a fever of infinities at the bottom of a black hole. Replacing them with a slightly modified set of rules suggests that a wormhole to another universe might exist in its place. But we do not have the evidence yet that those alternative rules are the right ones to use.

1 Mouth

All wormholes have two openings, often called 'mouths' - you enter one and exit the other.

2 Ordinary space

The 'flat' areas that lie far away from the mouths are known as ordinary space.

4 One mouth per universe

This time the entry mouth is in a different universe to the exit mouth.

3 Throat

The tunnel that connects the two mouths is known as the 'throat', but it's hard to keep it open.

5 Journey to the multiverse

Rather than connecting two points in the same universe, the throat is a portal to a parallel universe.

The hunt for wormholes

WHERE SCIENTISTS THINK WORMHOLES MIGHT EXIST

Where these portals through space-time could be hiding

Centre of the Milky Way

In 2015 Italian researchers suggested there could be a wormhole lurking in the centre of the Milky Way some 27,000 light years away. Ordinarily a wormhole would need some exotic matter to keep it open, but researchers believe dark matter might be doing the job.



© ESO

Inside a black hole

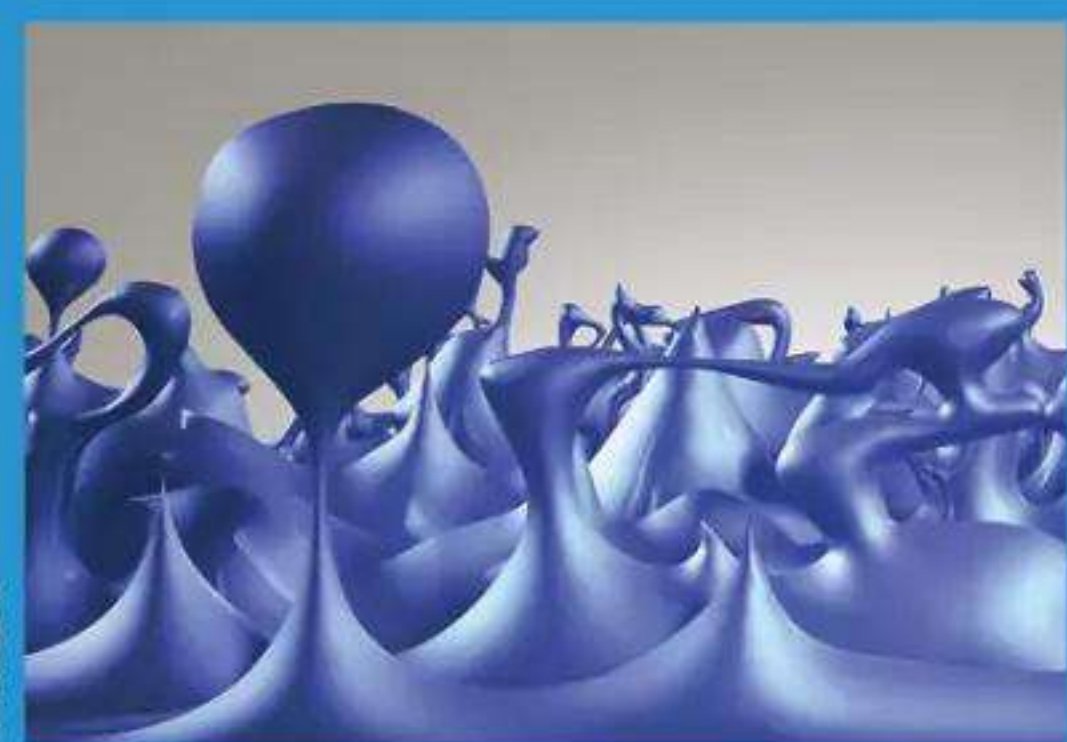
Rather than having a singularity at the centre as general relativity predicts, some researchers believe we'd find a wormhole - one that could allow us to make the journey from *Interstellar* a reality. However, the jury is still out on whether it would be big enough for a human to traverse.



© NASA

Quantum foam

Even empty space isn't truly empty - on the smallest scales it is a cauldron of bubbling energy popping in and out of existence. Some think fleeting virtual black holes may be being created all the time in this 'quantum foam'. However, we'd need a lot of energy if we wanted to make one permanent.



© NASA

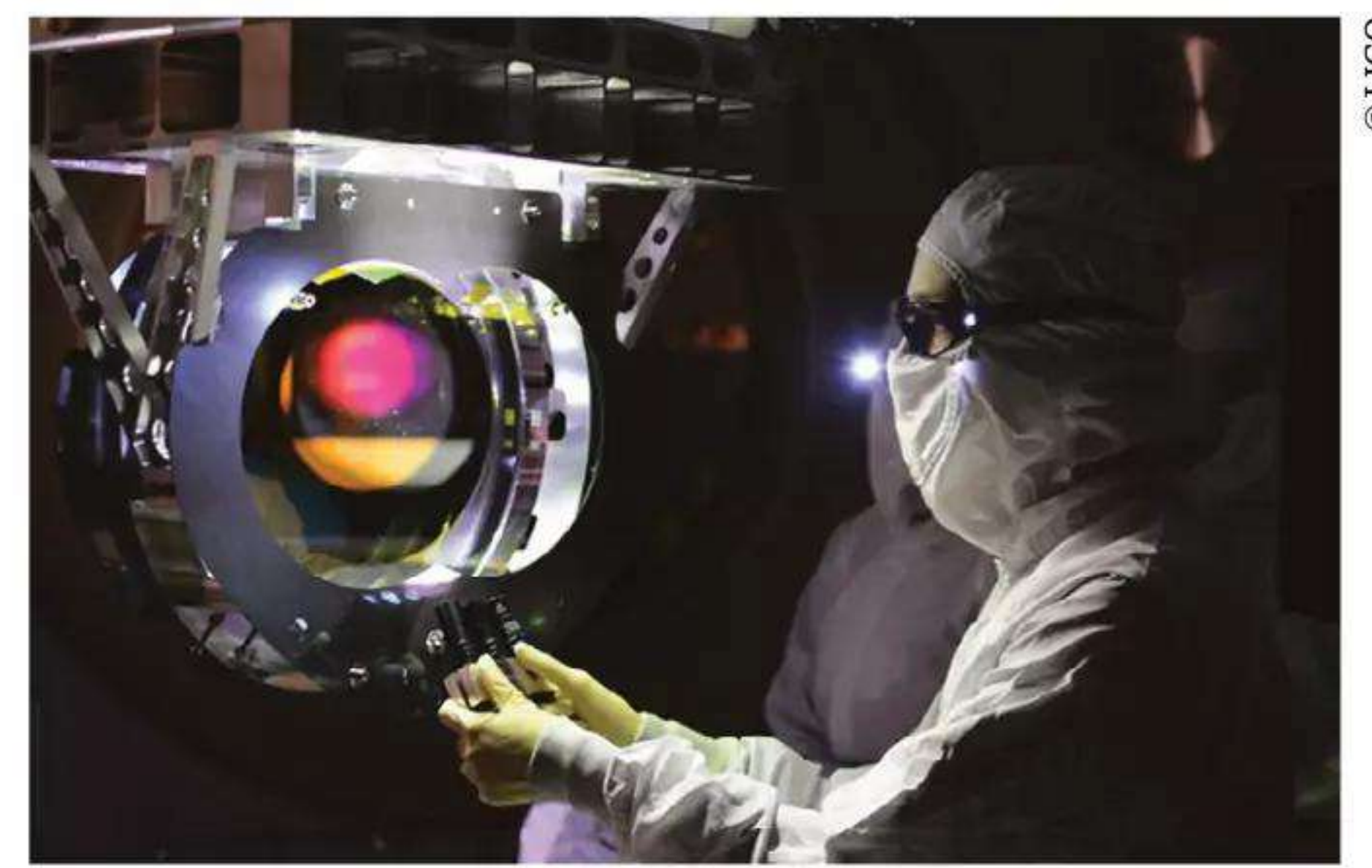
Right: A technician at the LIGO experiment, which announced it had detected gravitational waves for the first time in 2016

Below: LIGO at Livingston, Louisiana, listens for faint whispers of the most energetic events in the universe

are because the Sun's gravity bends their light on its way to us. Newton and Einstein's competing pictures of gravity predicted different amounts of bending, allowing us to see who was right. Einstein came out on top: massive objects do indeed bend the space-time around them.

Imagine space as a vast sheet of paper. You live at one end and you want to travel to the other end. Ordinarily you'd have to trudge across the entire length of the page to get there. But what if you folded the paper in half instead? Suddenly where you are and where you want to be are right next to each other. You simply have to jump that tiny gap. We call these objects wormholes because it is like a worm trying to navigate its way around an apple. To get from the top to the bottom it has two choices: crawl around the outside or chew a shortcut through the middle.

Until recently our chances of finding these objects - if they even exist - were slim at best. But that changed in February 2016 when the scientists behind the LIGO (Laser Interferometer Gravitational-Wave Observatory) experiment, based in the US, announced the first-ever detection of gravitational waves. These are tiny ripples in the fabric of space-time, predicted by general relativity, which spread out through the universe much like ripples on a pond. "It was a game-changer," says Vitor Cardoso, a physicist at the University of Lisbon in Portugal. Two black holes - each about 30 times



© LIGO

more massive than the Sun - had rammed into each other 1.3 billion years ago. Their violent crash sent a tsunami of gravitational waves roaring out through space-time, eventually reaching the LIGO instrument in September 2015.

Cardoso's research suggests that two colliding wormholes would produce a similar burst of gravitational waves. Excitingly, however, he says the resulting waves would be slightly different, allowing us to distinguish between black holes and wormholes. The key here is what's known as the 'ringdown' - the way in which the gravitational waves die away after the initial collision. It's similar to the way the sound of a ringing bell fades over time. "With two colliding wormholes you would see the ringdown - just like you see for black holes - but if your detector is very sensitive then seconds, or tens of seconds, after the main burst you would see something different," he says. This is due to the



© LIGO

HOW WORMHOLES ARE MADE

If these space-time tunnels do exist, what would they look like and how would they come into existence?

1 Collapse of the core

When a gigantic star – with a mass much more than 20 times the mass of the Sun – dies, sometimes a black hole is formed. When we refer to a star dying, we mean that it no longer has any nuclear fuel to burn, and this means that gravity is unable to override an outward force. The core has no choice but to collapse in on itself in the catastrophic explosion of a supernova. The devastated star's outer layers are expelled into space while the core continues to shrink in size.

2 A cosmic plughole

Shrinking smaller and smaller over thousands of years, the core pales in significance compared to its former stellar glory, collapsing into an even smaller size. However, while it has shrunk to a speck, all of its mass is now concentrated in a very small area. Meet what is known as a singularity, which might be small, but it is so heavy that it has the ability to bend space-time. Not even light can escape the gravitational pull of the singularity. Gravity is essentially the effect that a heavy object has on the fabric of space-time that can be found around it. Picture a sheet held loosely at each of its four corners. If you place a heavy object onto that sheet, you'll find that it makes a dent. Anything in the vicinity of the object that made the dent will fall towards it – just like gravity.

3 The makings of a doughnut

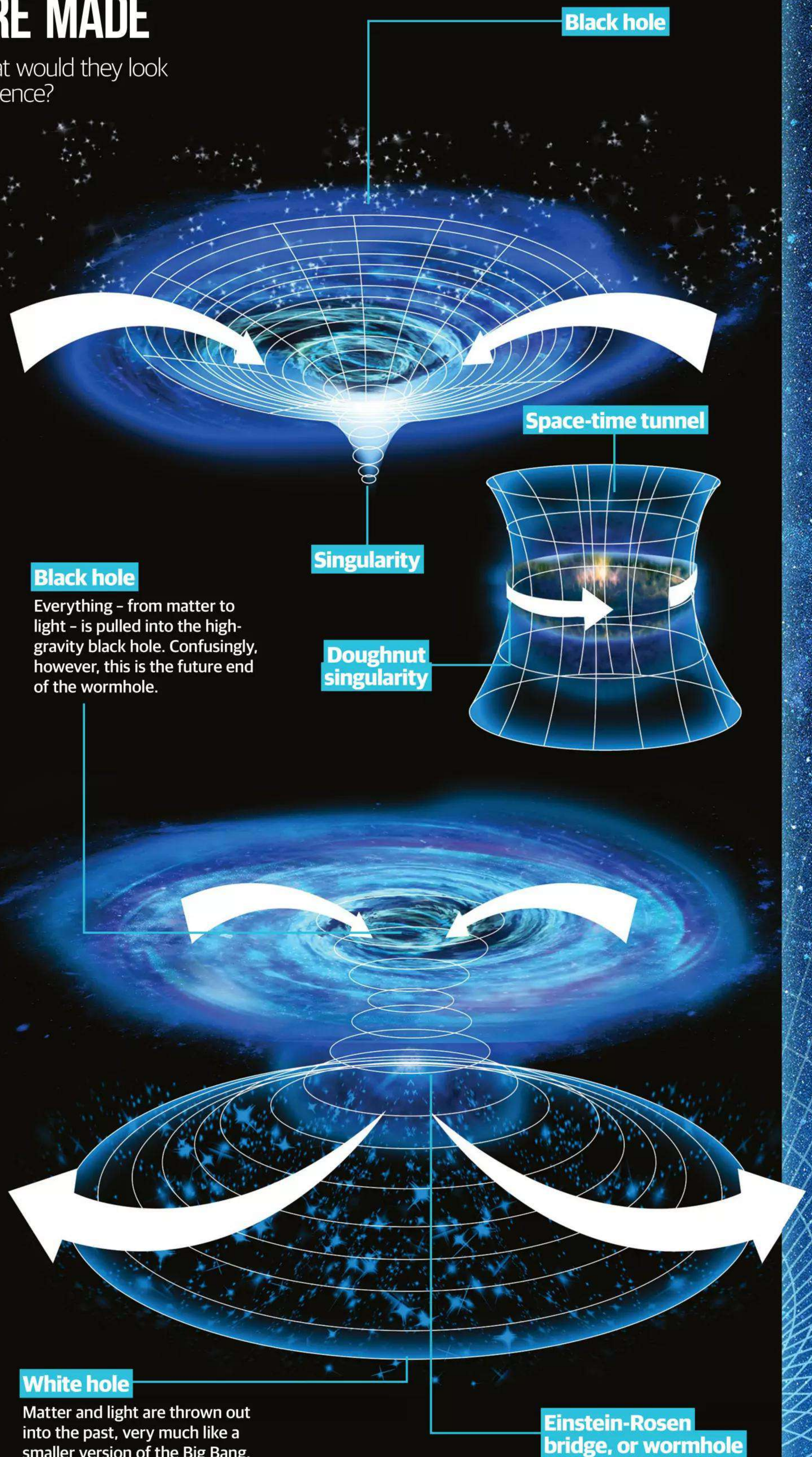
A star's core can still be found to be spinning when it decides to collapse. Crumbling to the minuscule yet hefty singularity, it begins to rotate faster and faster. It spins so quickly that what's left of the star's material spreads out and is moulded into a doughnut. Space-time is no longer focused on a single point; it's now being wrapped around this space ring, creating a tunnel.

4 Punching through space

The tunnel being made punches its way through the fabric of space-time, and almost in a state of reversal it emerges backwards in time and into the past. This tunnel, which could feasibly work its way into another parallel universe, is called an Einstein-Rosen bridge, or a wormhole. Any matter that is grabbed by the black hole is passed through this tunnel.

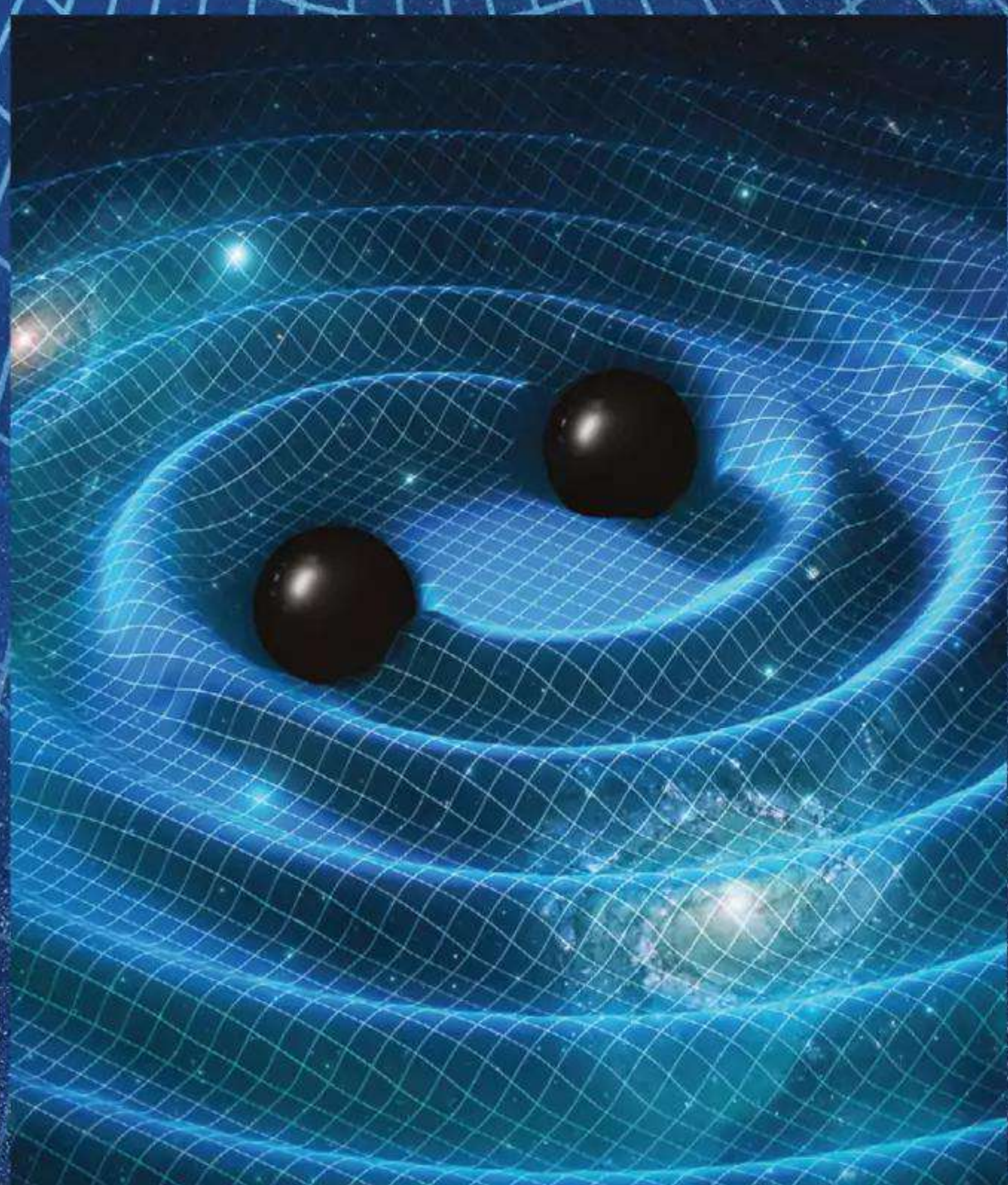
5 Meet the white hole

If you were to travel through a wormhole, you would reach its far side, which can be likened to a black hole in reverse: the white hole. Matter pulled in by the black hole will emerge from the singularity found at the white hole's centre and be released back into space. Just as nothing can escape a black hole, it's not possible to enter a white hole.



HOW DO WE KNOW IF WE'VE FOUND A WORMHOLE?

There are several clues to look out for if we find a candidate for a space-time portal



Gravitational-wave ringdown echo

The gravitational waves from colliding black holes die away very quickly, but two colliding wormholes would produce an echo detectable with the next generation of experiments.



Microlensing

If a wormhole passed in front of a distant star it would bend the star's light slightly in an event called 'microlensing'. This technique has already been used to find rogue planets.



Heading into one

Some scientists believe that black holes are actually wormholes in disguise. It's a risky endeavour, but sending something into one would let us know for certain if wormholes really do exist.



Left: Einstein's general theory of relativity suggests that what we experience as gravity is simply a bending of space and time

nature of black holes – gravitational Goliaths that swallow anything that gets too close. The ringdown of colliding black holes always gets quieter, quickly fading away to silence. But with colliding wormholes, after the silence you get an echo – a sudden, late signal as the gravitational waves bounce off the wormholes' surface. You can't get that with black holes as they swallow everything.

Unfortunately LIGO currently isn't sensitive enough to pick up these late changes. However, researchers are upgrading LIGO's instruments, and it could be possible in "ten years from now or so," Cardoso says. Another exciting project on the horizon is the European Space Agency's (ESA's) Laser Interferometer Space Antenna (LISA). This is a gravitational-wave observatory in space that has a tentative launch date of 2034. However, in 2015 the ESA launched LISA Pathfinder – a test mission to develop certain key technologies that are vital for LISA's success. In April 2016 the ESA announced

that LISA Pathfinder had indeed shown that LISA was feasible.

But ringdowns of collisions might not be the only route to finding a wormhole. Diego Rubiera-Garcia, Cardoso's former colleague at the University of Lisbon, has another idea. He's been studying what goes on deep inside a black hole. The conventional picture of black holes, as described by general relativity, has all the infalling mass squeezed down into an infinitely small, infinitely dense point – a singularity. "Any observer who approaches this point is destroyed," says Rubiera-Garcia. "After that you will disappear from space-time... there is nowhere else for you to go." It is at this singularity that general relativity breaks down – its equations stop making sense. This leaves many physicists confident that we need a new set of rules to replace general relativity in such an extreme environment.

And that's where wormholes come in. When Rubiera-Garcia applied one of the alternative sets of rules to the physics of black holes, the singularity disappeared, and the mathematics yielded a wormhole in its place. "Then it would be possible for an observer to go through this wormhole and cross to another region of the universe," he says. The trouble is that this shortcut through the cosmos might just be a phantom of the mathematics: the alternative to general relativity that Rubiera-Garcia

"TO EVEN CREATE A WORMHOLE REQUIRES EXOTIC MATTER THAT WE HAVE NEVER SEEN HERE ON EARTH"

VITOR CARDOSO

used to find it might not be how our universe really works. As with all good scientific theories, it needs to be tested, just as Einstein's was in 1919. That's where gravitational waves come back in.

Once we have built up a significant library of gravitational-wave detections, we can trawl through the data looking for departures from what general relativity predicts we should see. If these departures are found - and they match what the alternative theory predicts - it could signify that wormholes do indeed lurk inside black holes. The first detection of gravitational waves has ushered in a new era, one in which we may well find out that wormholes aren't just science fiction after all.



Colin Stuart
Astronomer & space science writer
Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour: 15347 Colinstuart.

Below: The ESA's Laser Interferometer Space Antenna (LISA), due to launch in 2034, is a gravitational-wave observatory that will continue the search for wormholes

IF THEY EXIST, COULD WE TRAVEL THROUGH A WORMHOLE?

YES

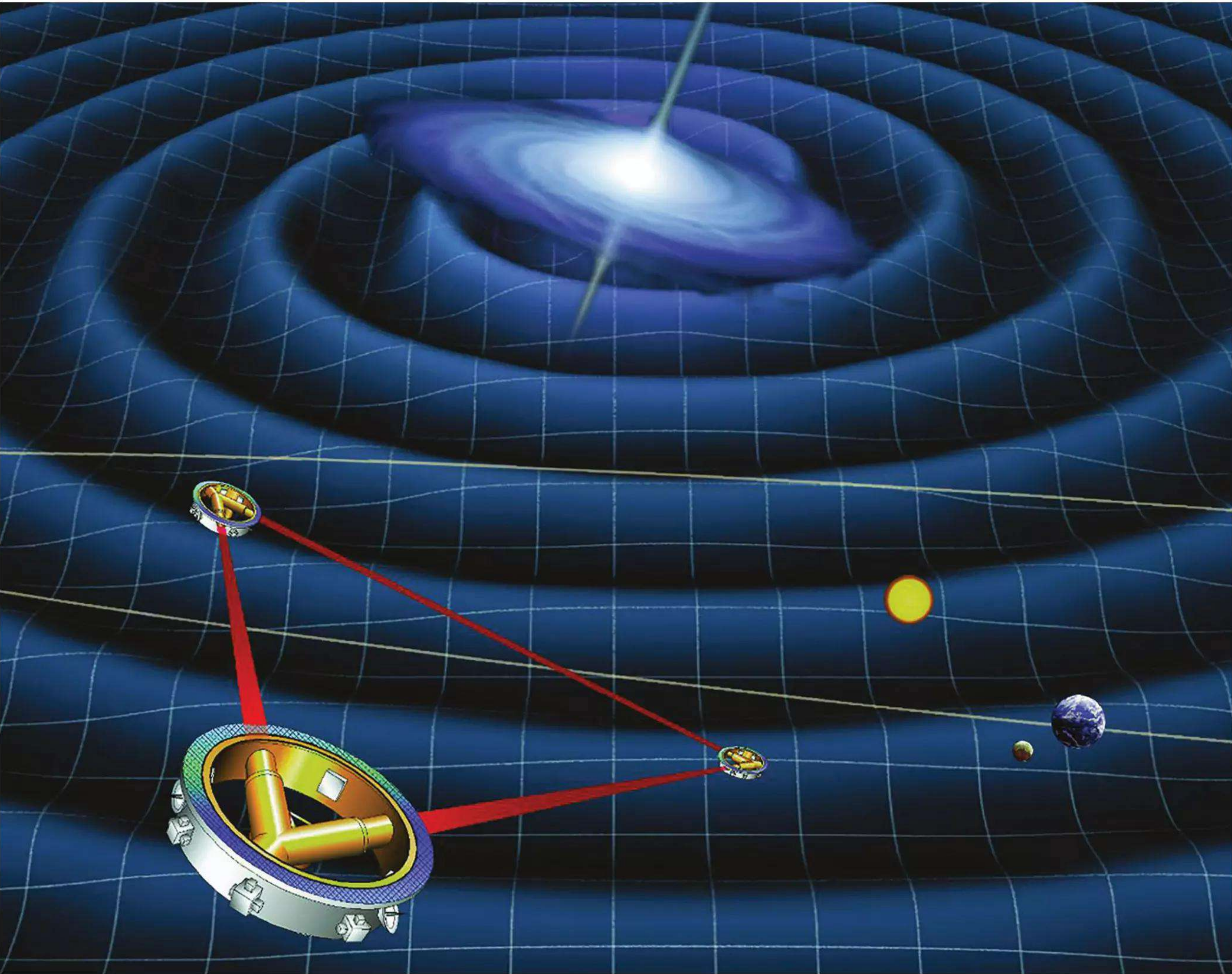
"The possibility of using wormholes to travel is not completely excluded at a theoretical level. However, to even create a wormhole requires exotic matter that we have never seen here on Earth."

Vitor Cardoso
University of Lisbon, Portugal

NO

"The problem is that usually these wormholes are very small, and when I say small, I mean really, really small, so it is not possible for a real observer to pass through that wormhole."

Diego Rubiera-Garcia
Complutense University of Madrid, Spain



SCIENTISTS SPOT MAGNETARS' MISSING LINK

These magnetic stars might be more like
pulsars than originally suspected

Researchers have apparently found a 'missing link' between two types of pulsars. Pulsars are fast-spinning neutron stars, the superdense, collapsed cores left over from the explosive deaths of massive stars. Pulsars emit beams of radiation from their poles that appear to pulse when they're observed from Earth, hence the name. Pulsars don't actually pulse, though - that's an effect of their rotation.

Scientists had thought that two different kinds of pulsars - magnetars, which sport extremely powerful magnetic fields, and rotation-powered pulsars - emit their beams in different ways. But a new study suggests that these extreme objects have more in common than was previously presumed. "Our study has given us new understanding of the neutron stars with high magnetic fields," said Chin-Ping Hu, a visiting researcher at the RIKEN Cluster for Pioneering Research in Japan.

On 12 March scientists discovered a new gamma-ray burst with the Burst Alert Telescope aboard NASA's Neil Gehrels Swift Observatory, a space-based gamma-ray telescope. The object, J1818.0-1607, which the researchers believe is a magnetar, immediately inspired follow-up X-ray observations with the Neutron star Interior Composition Explorer (NICER), an instrument aboard the International Space Station (ISS).

Using NICER, the researchers found that the magnetar has a pulsation period - the time between stellar pulsations - of 1.36 seconds, the shortest ever spotted in a magnetar. They also found that the magnetar is fairly young, forming just 420 years ago - from our perspective, at least. The object lies 16,000 light years from Earth, so everything astronomers are observing with the magnetar happened long ago. Strangely they also found that this magnetar's X-ray emission was lower than that of other magnetars.

Notably, the magnetar was exhibiting 'spin-down behaviour'. Because of this the team think that its emissions were at least in part powered by rotation. This is significant because typically rotation-powered pulsars are thought to be the ones that produce beams through rotating. This finding draws the two objects closer together and expands scientists' understanding of how and why these objects produce their beams. Additionally, Hu added: "Recent radio observations suggest that magnetars may be a cause of mysterious phenomena called fast radio bursts. We look forward to investigating further."

"WE HAVE A NEW UNDERSTANDING OF THE
NEUTRON STARS WITH HIGH MAGNETIC FIELDS"

CHIN-PING HU

Below:
Magnetars are
dense cores of
massive stars
with strong
magnetic fields





SHEDDING LIGHT ON PHANTOM ENERGY

AND THE DARK SIDE OF THE UNIVERSE

Understanding the 'undetectable' cosmos could well lead to significant changes in some highly cherished theories that govern space-time

Reported by Paul Cockburn

We live in an age of precision cosmology. As we continue to observe and study the universe around us using ever more precise instruments and increasingly sophisticated data-processing systems, the findings have invariably proven to be unexpected - if not frankly bizarre. Perhaps the most famous of these findings was the gradual realisation that everything we can see in the universe - every dust cloud, asteroid field, planet, star, nebula and galaxy cluster - simply doesn't have sufficient mass to ensure that the universe behaves in the way it clearly does - at least according to the standard model of cosmology, grounded in Einstein's general theory of relativity.

A potential solution to this problem was first suggested as far back as the early 1930s with dark matter, so called because it must consist of a material that neither emits nor reacts with visible

light - or indeed any part of the electromagnetic spectrum. And so the dark side of the universe was born.

More recently - albeit indirectly by detecting its gravitational influence - astronomers have learned more about dark matter, not least the astounding fact that it must make up around 23 per cent of the total mass in the universe. Nevertheless, once dark matter is added to Einstein's theory, it fits everything from star formation to the fact that galaxies don't simply fly apart due to their rate of spin.

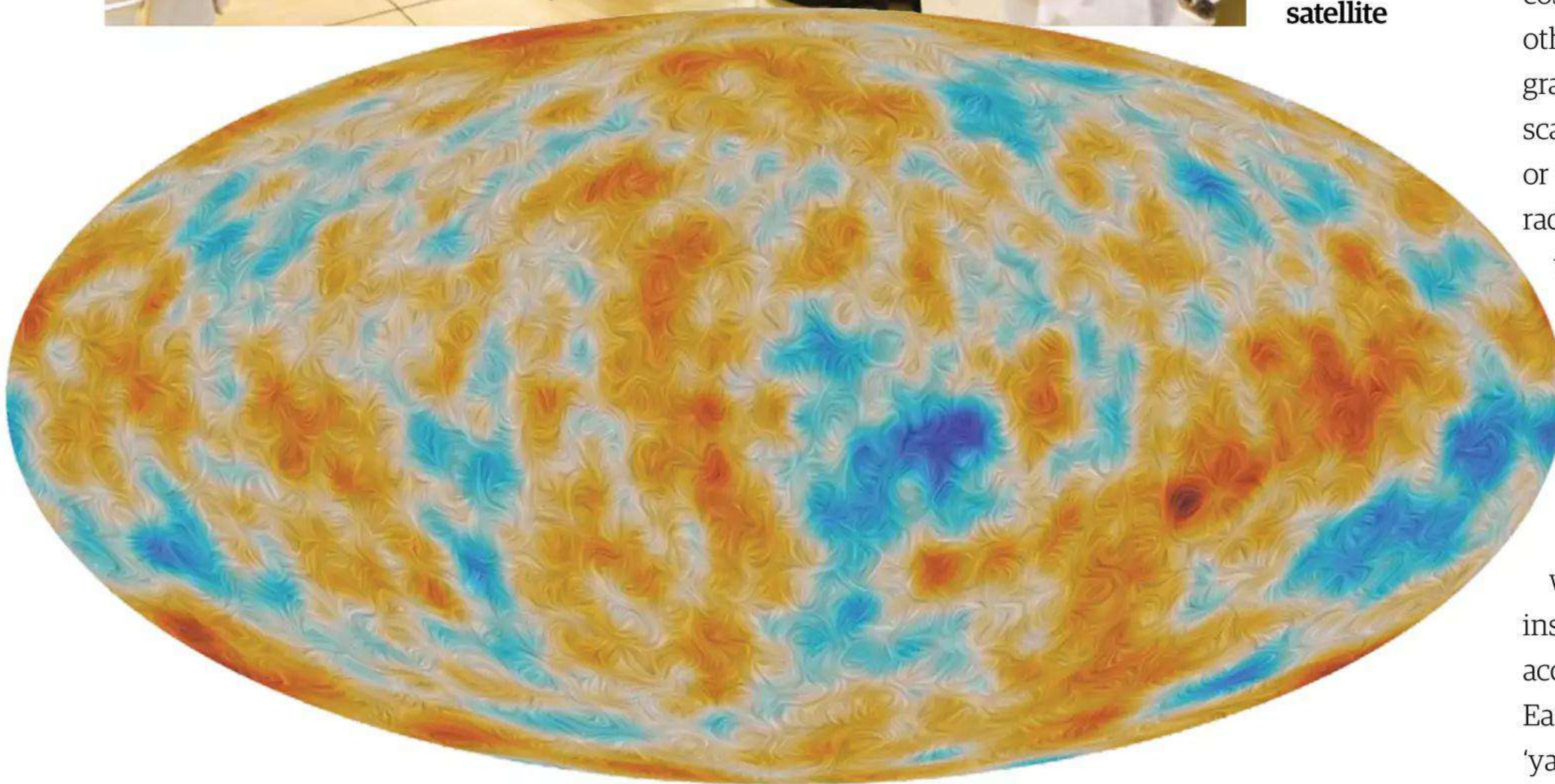
But it is not just about dark matter. In 1929 observations made by Edwin Hubble revealed that the universe appeared to be expanding - that most galaxies were moving away from us, and that those which were furthest away were doing so the fastest. The correlation between the distance and speed at which the universe is expanding was soon dubbed the Hubble



“DISTANCES BETWEEN COSMIC OBJECTS ARE LIKELY TO DOUBLE IN ANOTHER 9.8 BILLION YEARS”

Left: The European Space Agency's (ESA) Planck Observatory measured the cosmic microwave background radiation of the cosmos

Below: A snapshot of the oldest light in the universe, as seen by the ESA's Planck satellite



constant, but don't let that name fool you – as it turns out, it's neither constant nor unchanging as the universe expands!

When it came to what was causing this expansion, astronomers eventually opted for the idea of dark energy as a solution – an unknown form of energy permeating all space which ensures matter increasingly repulses matter. Again, for Einstein's theory to work, this dark energy needs to account for more than two thirds – about 73 per cent – of the energy in the universe, a proportion that might strike some as wishful thinking.

Nevertheless, in more recent decades, indirect evidence has been found that supports the idea of dark energy, not least when astronomers compare distance measurements and their relation to the redshift in the light detected from the objects. The fact that the universe appears to have expanded more in the latter half of its life is one such example

of evidence in favour of dark energy. Dark energy may well explain why, going by measurements taken of the direction patterns in the cosmic microwave background (CMB), it appears the universe is close to being flat, which would only be possible if some form of unknown energy existed to balance its overall density against an otherwise insufficient amount of mass – matter and dark matter combined – in the universe.

However, dark matter and dark energy now appear insufficient to keep the standard model of cosmology perfectly in sync with how the actual universe is observed to work. Cosmologists are increasingly talking of 'dark radiation' and a specific form of dark energy that's been dubbed 'phantom energy'. This astronomical phantom energy is not to be confused with the phantom energy – or 'vampire energy' – drawn by electrical equipment from the grid when switched off but still plugged in.

Increasingly there is also talk of 'dark' or 'modified' gravity, a somewhat more drastic approach that suggests we simply don't fully understand the fundamental nature of the universe and that gravity – especially at huge cosmological scales – doesn't actually follow the rules laid down by Einstein's general theory of relativity.

Robert Caldwell is a theoretical physicist at Dartmouth College, New Hampshire, whose research focuses on addressing questions about the basic properties of the universe. "I guess they've really only been discussed since about 2000," he explains. "Dark energy and dark gravity are both proposals to explain the significantly accelerating cosmic expansion, which can't be explained otherwise. Some people have suggested that maybe gravity has a different description on cosmological scales, so that goes under the name of modified or dark gravity – I kind of like 'dark gravity'. Dark radiation – that's a funny one. I guess really where that comes in is the gap between the 'allowed' amount of radiation in the early universe and the amount we can account for."

A recent spur for talking about these newer aspects of a 'dark' universe was a scientific paper, published in June 2016, written by Adam Riess of Johns Hopkins University, along with the support of 14 coauthors from 11 research institutions around the globe. Based on the most accurate calculations of the distances between Earth and 19 different galaxies – relying on the 'yardsticks' of more than 2,000 variable Cepheid stars and Type 1a supernovae – the paper's findings were startling. According to the study, the revised speed of the expansion of the universe is 73.2 kilometres (45.5 miles) per second for every 3.26 million light years – that is, every 3.26 million light years further away we look, we find the universe is expanding 73.2 kilometres (45.5 miles) per second faster. At this rate, distances between cosmic objects are likely to double in another 9.8 billion years.

The challenge this refined figure poses, however, is that it doesn't fit the expansion rate predicted from wider measurements made of the afterglow from the Big Bang – the cosmic microwave background – as measured by the European Space Agency's Planck satellite. In fact, the difference is three to four times the 'uncertainty' factored into the latest figures.

Simply put, the paper suggests that the universe is currently expanding some nine per cent faster than it should be, at least according to the astronomers' predictions. "Either something else

PHANTOM ENERGY AND THE EXPANSION OF THE UNIVERSE

This mysterious form of dark energy could very well cause our cosmos to end by being torn apart

1 The Big Bang

Some 13.8 billion years ago, the universe began in a rapid expansion that originated from an area of high temperatures and high density.

2 Universe begins to inflate

Not long after the birth of the universe, an inflationary period begins and ends within much less than a second. Today the cosmos continues to expand, but at a much slower rate.

4 The first stars

Some 300 million years in, stars begin to burn, creating heavier elements from hydrogen and helium. The very first stars are thought to be Population III stars, which are extremely hot, massive and contain next to no metals.

6 Acceleration increases

7

3 The Dark Ages

For 150 million years the universe is transparent, without any large-scale structures. During this time the only real radiation was the so-called hydrogen line - when there's a change in the energy state of the neutral hydrogen atoms.

5 Galaxies are made

Large volumes of matter collapse to form galaxies. The very first galaxies are thought to have been well in place some 400 million years after the Big Bang. These young galaxies coalesced with others to form giant galactic structures.

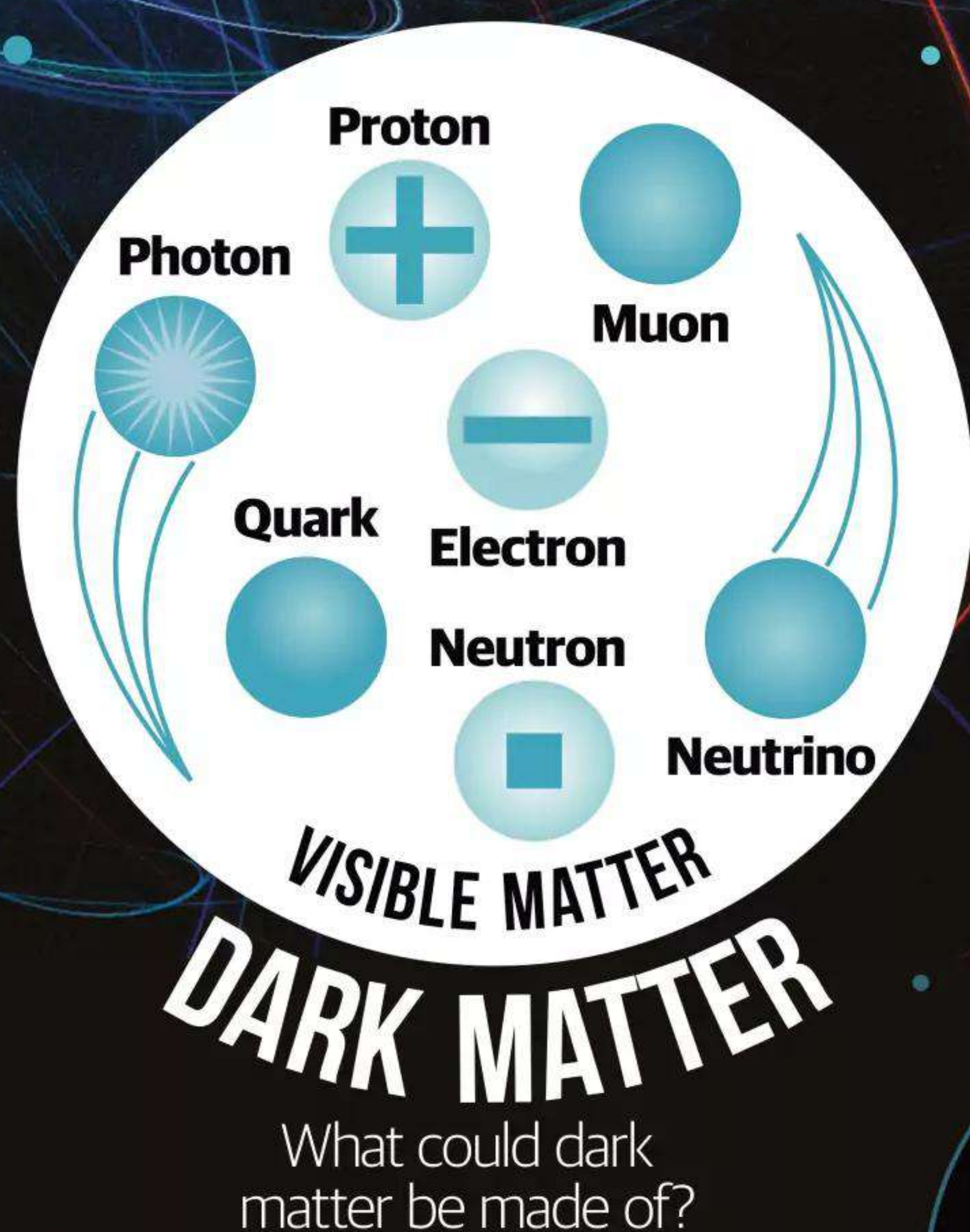
7 Phantom energy tears space apart

Some scientists believe that phantom dark energy - a hypothetical form of dark energy - will cause space-time to accelerate beyond the speed of light, leading to the universe ending in a Big Rip.

Right: Some 8,000 galaxies ensure the Shapley Supercluster is the largest structure in our 'local' universe

DARK MATTER'S RADIATION AND GRAVITY

Whatever comprises dark matter, even darker elements could be responsible for its behaviour



Dark photons

Another proposed 'dark force carrier' for dark matter, dark photons are elementary particles that could be seen by mixing with the particles of light we know as photons, along with how they affect the interactions between known particles.

Axion

These particles, if they exist and have a low mass, could be the primary component of cold dark matter.

STERILE NEUTRINO

The sterile neutrino doesn't interact with any of the fundamental forces that form the Standard Model of particle physics - that is, electromagnetism and the weak and strong nuclear forces, save gravity. They are a feasible explanation for what comprises dark matter since they do not interact with either electromagnetic radiation or matter, except through gravity.

Gravitino

Another suggested candidate for dark matter, the gravitino is partner to the hypothesised graviton - the particle that supposedly explains the existence of gravity.

DARK RADIATION

Whatever particle comprises dark matter, some believe that dark electromagnetism mediates the interactions of its constituents.

DARK GRAVITY

Dark gravity is thought to be the gravity produced by dark matter. Unlike the gravity that we experience on Earth, dark gravity is repulsive.

Higgsino

The super-partner of the Higgs boson, if the higgsino comprised dark matter then it would have a mass of 1.783×10^{24} kilograms, which is massive for a particle.

Dark neutrons

Dark electron

WIMPs

WIMPs, also known as weakly interacting massive particles, comprise of new elementary particles that interact through gravity and other forces which may not have been discovered yet.

is missing, as in there's a new type of substance we don't know, or the things we already know of are really weird and crazy and something funny is going on," explains one of the paper's authors, Dr Brad Tucker from the Mount Stromlo Observatory at the Australian National University. "We either add in something new or we really have to figure out what we think about dark matter and dark energy and what they are."

"While there have been published doubts raised about the accuracy of some of this CMB data, taken at face value it appears we may not have the right understanding, and it changes how big the Hubble constant should be today," Riess said at the time. "This surprising finding may be an important clue to understanding those mysterious parts of the universe that make up 95 per cent of everything and don't emit light, such as dark energy, dark

matter and dark radiation." Given its breadth and scope, astronomers around the world have taken the findings of Riess and his colleagues very seriously. After all, in 2011 Riess had shared the Nobel Prize in Physics for the initial discovery that the universe wasn't just expanding, but that the rate at which it was doing so was also increasing.

Professor Erik Verlinde of the University of Amsterdam has spent much of his time since 2010 attempting to develop a totally new theory of gravity, one that explains such observations without the need to invoke the likes of dark matter and dark energy. This resulted in his theory of 'emergent gravity', so called because gravity is not a fundamental force after all, but an 'emergent' phenomenon, similar to temperature emerging from the movement of particles. This sits somewhat better with quantum mechanics, the physics of the

very small, than the general theory of relativity, the physics of the very big, which has long been a problem for those looking for a so-called 'theory of everything'. An international survey looking at the gravitational lensing caused by galaxies, published in the December 2016 issue of the *Monthly Notices of the Royal Astronomical Society*, found that Verlinde's equations could explain the observations without the need for dark matter. That was just emergent gravity's first test, however, and it's by no means over for Einstein just yet.

There is an understandable reluctance to totally let go of both Einstein's theory of gravity and the well-established data on the CMB. The former may be found to be incomplete - but that's not the same as it being wrong. It's little surprise that so many astronomers have opted for there being some unknown physical phenomenon responsible for

THE HUNT FOR THE STERILE NEUTRINO

If these tiny particles exist, then the IceCube Neutrino Observatory, built under the ice of the South Pole, is one of our best chances of finding them



© Adrian Mann

1 Bedrock

IceCube rests just above the Antarctic bedrock, hoped to help block out neutrinos from below. Buried some 2,500 metres (8,200 feet) below the surface, IceCube uses the Earth itself as a filter to block out more locally produced cosmic rays while letting neutrinos in.

2 Boreholes

Over 80 individual strings of detectors gather data, which is sent by satellite to a data warehouse in America. About 100GB of time-stamped data is collected every day.

4 Deep down

The Digital Optical Modules, the top detector on each string, are nearly 1.5 kilometres (0.9 miles) below the surface ice.

3 IceCube Observatory

The IceCube South Pole Neutrino Observatory is located close to the South Pole, Antarctica.

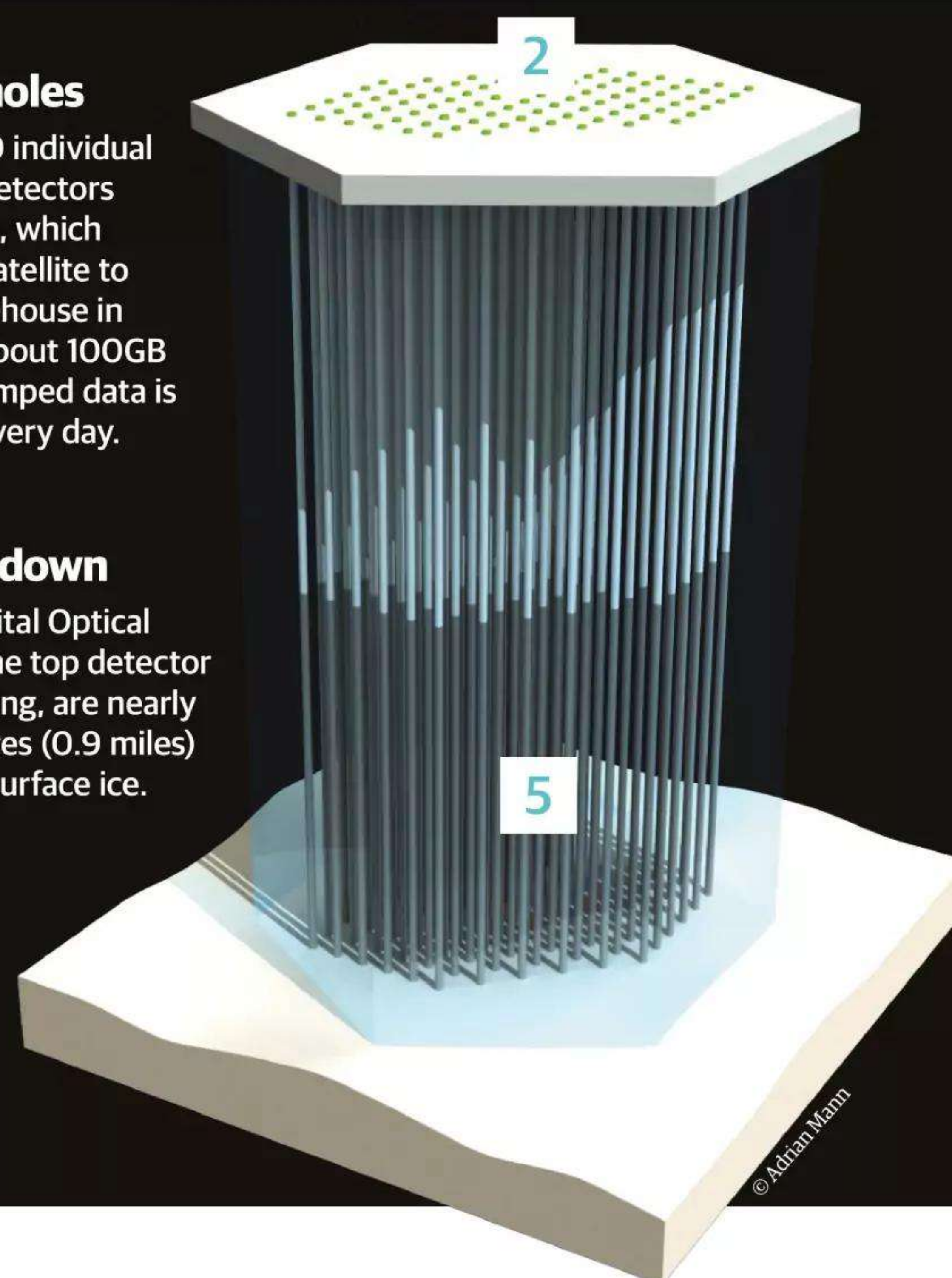


5 Looking for a flash

There are 60 detectors on each string, which are 17 metres (56 feet) apart. There are more than 5,000 individual detectors.



© IceCube/NSF



© Adrian Mann

the discrepancy between theory and observations. With dark energy already assumed to be the foot on the accelerator causing the universe to expand, it's not a huge step to suggest ways in which it may actually be pushing galaxies away from each other with even greater - or increasing - strength than originally expected.

However, another idea with growing support is that this greater-than-expected expansion of the universe is down to previously undiscovered subatomic particles that, in their early history, travelled close to the speed of light. Collectively these are termed 'dark radiation' and include a proposed 'fourth flavour of neutrino', delightfully known as 'sterile neutrinos'.

What is needed, of course, is evidence. At the moment the rate of expansion of the universe is the only significant, albeit indirect, sign of dark

Right: A technician works on one of the Digital Optical Module sensors of the IceCube Observatory in a clean room



© IceCube/NSF

Phantom energy

energy, and specifically phantom energy. “The rate of acceleration is greater than in other dark energy models or theories of dark energy,” says Caldwell. “Usually that’s expressed in terms of the equation of state of dark energy; for phantom energy the equation of state is more negative than a certain critical value. Putting together a really good measurement of the rate of expansion is the primary way that something like dark energy or phantom energy is being tested.

“Dark gravity you can begin to constrain within a particular theory, I suppose, doing the same types of tests you would for phantom energy. But if you really want to test this idea of dark gravity, you have to look at some phenomena where you’ll see an appreciable difference,” Caldwell continues. “In many of the theories that people have proposed, phenomena like gravitational lensing should look different in a universe described by dark gravity rather than general relativity. And so people are looking for ways to use weak lensing experiments, where instead of the lens being the Sun and the source of light being a star in the galaxy – as happened in 1919, which proved Einstein’s theory correct – the lens is a cluster of galaxies and the light is much bigger.”

Nevertheless, Caldwell still thinks we need to await a new idea or technological breakthrough. “The problem with a lot of these tests or theories we’re going after is that in each case there’s a gap and we’ve filled it with something,” he says. “Observers are doing their duty of carrying out the measurements to the best of the technology they have and developing new techniques, pushing technology forward, but few of these theories have a unique prediction that would say: ‘You just need to measure this one thing and forget the rest, and then you’ll see.’ That’s a bit of a problem; I guess that makes it harder. We’re still waiting for either that real breakthrough idea or measurement.” Still, he’s just as committed as most astronomers to the idea of there being these dark aspects to the universe. “If I meet a cosmologist now who thinks that the whole dark energy-dark gravity thing is on the wrong track, then they’re just ignoring the evidence,” he says.

But what if some aspect of dark gravity proves that Einstein simply got it wrong? “If we discover a new gravitational phenomena, then we will realise that Einstein’s theory has a similar role to Newton’s theory,” Caldwell says. “That it’s a beautiful theory that leads to testable predictions with high accuracy, but it’s only valid in a certain domain, a certain range of validity – at which point it gives out to yet another theory.”



Paul Cockburn

Space science journalist

Paul has been writing about and keeping up to date with the latest research in science, technology and space for more than 25 years.

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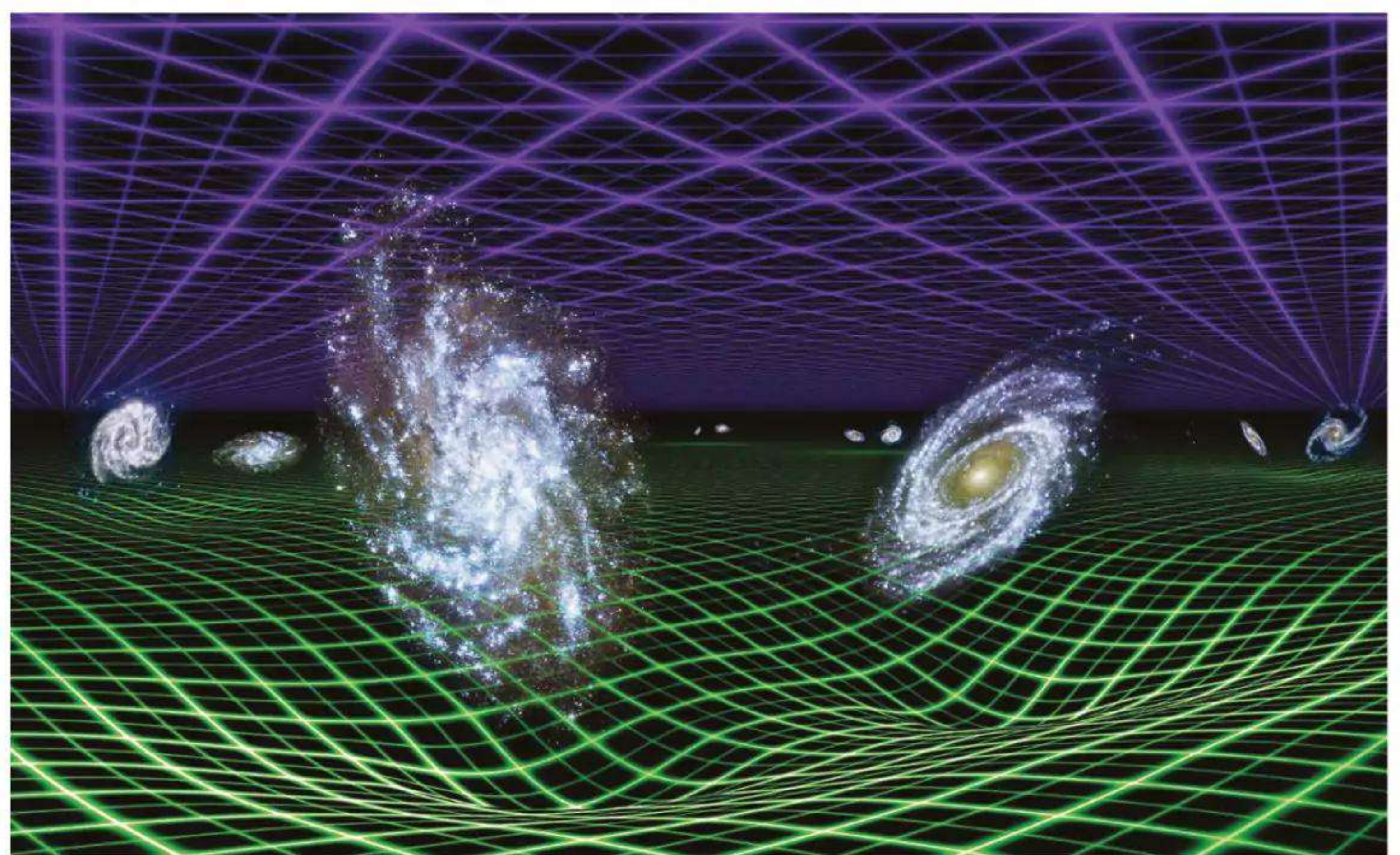


“IF I MEET A COSMOLOGIST NOW WHO THINKS THAT THE WHOLE DARK ENERGY-DARK GRAVITY THING IS ON THE WRONG TRACK, THEN THEY’RE JUST IGNORING THE EVIDENCE”

ROBERT CALDWELL

Above:
Pulsating
RS Puppis
is the kind
of star used
to measure
galactic
distances

Right: In
this artist’s
impression,
dark energy
is the smooth
purple grid
sitting above
the galaxies



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HISTORY OF NASA

NASA has been responsible for some of the most important advances humankind has made.

It has left footprints on our Moon and sent spacecraft beyond the limits of our Solar System.

Its Mars rovers, controlled remotely by human drivers here on Earth, search for life on the plains of the Red Planet; Hubble looks back through time and space towards the very beginning of the universe itself. No other organisation has ever gone beyond the boundaries of nationality and politics to embody humanity's curiosity, vision and ambition in the way that NASA has. This is the story of how and why it was created, of its greatest triumphs and darkest days.

HOW IT WORKS BOOK OF SPACE

Space has fascinated us from the earliest days of civilisation, and as we keep scratching the surface of the vast universe in which we live, our sense of awe and wonder continue to grow. With the technological advancements being made by the world's space agencies, we understand more than ever the things that are happening beyond our own planet. This new edition has been updated with more of the latest astronomical advancements, stunning space photography from the most advanced telescopes on the planet and glimpses at what the future of space exploration holds, taking you from the heart of our Solar System and out into deep space.

BOOK OF MARS

The history of Mars is intrinsically bound up with that of Earth's - some scientists even think that the original building blocks of life came from there. Meanwhile, the ESA's Mars Express probe, undeterred by the failure of its Beagle 2 lander back in 2003, recently beamed back some of the clearest images yet of a crater filled with water ice in the northern lowlands of what was once thought to be an arid world. The **Book of Mars** reveals what scientists know about the planet that has captured human imagination for centuries, examining the theories that may help us to understand it further and exploring how one day we could make it into another human home.

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Instant expert

HOW DOES A ROCKET WORK?

A rocket engine profits from one basic principle: as it propels material in one direction, it receives a kick in the other. Whether it's a child on ice skates who throws a stone forward and finds themselves gliding backwards or a modern rocket leaving Earth's surface, the physics of conserving momentum underwrites the drama.

Does the rocket need to have a flame to be effective? Not in principle. Some smaller thrusters have simply puffed vapour away from the direction they want to travel. Even a slow leak or evaporating water have provided a small kick to nudge a craft from its intended course. But a launch-worthy rocket engine uses what engineers have sometimes called a 'controlled explosion' to provide an incredible thrust. This is not because it ejects heavy objects, but because it ejects a furious stream of high-speed molecules.

To achieve this sort of rapid ejection, rocket engines achieve one of their primary engineering miracles. They bring swimming pools of combustible fuel and oxygen together via high-speed pumps. The fuel is typically either kerosene - like was used in the first stage of the old Saturn V, or in the newer Falcon 9 - or hydrogen, like in NASA's new Space Launch System. We may blow on a barbecue to feed it oxygen, but a rocket engine needs its own supply - especially as it climbs from the atmosphere. Carrying oxygen and hydrogen gas would require

far too much volume, so a rocket carries a greatly condensed version: super-cooled and liquefied oxygen, known as LOX.

The next engineering miracle follows, hidden within the engine's guts. It must bring cryogenic liquids, hundreds of degrees Celsius below freezing, rushing towards a combustion chamber firing thousands of degrees above boiling. Clever precirculation of the chilly liquids through the walls of the engine bell both warms the super-cold liquid and also keeps the metal of the bell from melting in the relentless blast.

"EVEN A SLOW LEAK OR EVAPORATING WATER HAVE PROVIDED A SMALL KICK TO NUDGE A CRAFT FROM ITS INTENDED COURSE"

1 Double pump

The two high-speed pumps take in their respective liquefied fuel and oxygen and begin to ramp up the pressure. This sends them on to the combustion chamber for the burning to begin.

2 Avoiding a meltdown

Due to the extreme temperatures created when burning these two propellants, the liquid fuel has to enter via a special passage that will stop the nozzle and combustion chamber from melting.

4 Ignite the fire

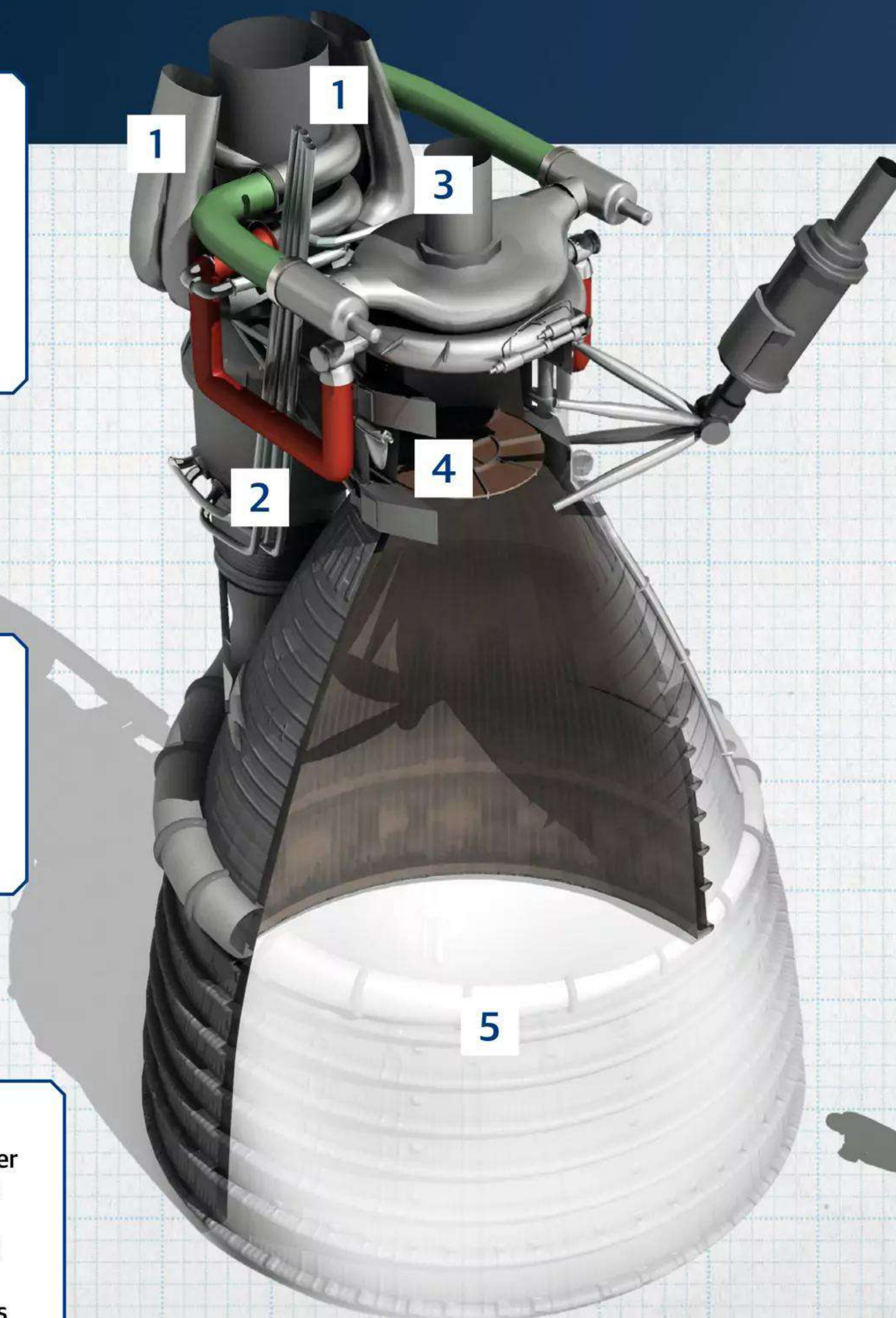
The combustion chamber is where the fire starts. The cooled fuel and oxygen meet to create a 'controlled explosion', reaching insane temperatures and pressures that are directed towards the throat of the nozzle.

3 Turning the cogs

After the fuel moves through the coolant passages, gaseous hydrogen travels from the combustion chamber to the turbine, which causes the turbopump to rotate, consequently turning the cogs that then operate the pumps.

5 The gift of thrust

The high-speed molecules are then directed out the end of the nozzle, creating the thrust that is needed to break the bond of gravity and send satellites, astronauts and spacecraft into space.





BIO **PROFESSOR** **BRANDON** **R. BROWN**

Brown is a professor of physics and astronomy at the University of San Francisco, California. Born in Houston, Texas – also home to the Johnson Space Center – Brown has a passion for understanding the physics that makes rockets functional, as well as science communication. In his 2019 book *The Apollo Chronicles*, Brown looks at the Apollo era of space travel from an engineering point of view.



SOLAR SYSTEM

What will happen to the Solar System when the Sun becomes a white dwarf?

For the last 4.5 billion years the Sun has provided warmth and light to Earth, thanks to a constant chain of nuclear reactions in its core. But what will happen to our planet, and the rest of our Solar System, when the Sun runs out of its nuclear fuel? In about 8 billion years the Sun will swell 200-times larger than its current size, engulfing most of the inner Solar System - Mercury, Venus and possibly Earth - and briefly baking the outer planets - Jupiter, Saturn, Uranus and Neptune.

After completely exhausting its fuel reserves, the Sun will shed its outer layers, leaving only a tiny, dense remnant core called a white dwarf glowing from the Sun's leftover heat. This transformation sets off a series of changes for the surviving planets in the outer system. After a short period of intense radiation, the white dwarf will cool rapidly, freezing the outer

planets. The loss of the Sun's outer layers also triggers gravitational instabilities, leading to close encounters between planets, asteroids and comets, sending some of these planets perilously close to the white dwarf star while ejecting others from the system. But despite all of this chaos, planets may still find a way to survive - and even be hospitable to life.



Dr Andrew Vanderburg is an assistant professor at the University of Wisconsin-Madison

Above: The white dwarf star Sirius B compared to Earth

"IN ABOUT 8 BILLION YEARS THE SUN WILL SWELL 200-TIMES LARGER THAN ITS CURRENT SIZE" ANDREW VANDERBURG

HUNT FOR LIFE

Is it possible that all signs of life on Mars could have been wiped from the planet?

A recent study shows that a short-term exposure to acidic fluids can modify the long-term preservation of biomarkers - biological indicators of life - embedded in clays on the surface of Mars, therefore explaining why the search for the molecular remains of extinct life on Mars has proven to be so challenging. We know that life can thrive very successfully in a wide variety of acidic environments here on Earth. The problem with the acidic fluids is not for the origin and development of life, but for the preservation of the remains of that life in the clay sediments. The acid fluids can modify the internal structure of clays, and hence their capability to host and protect organics inside. We expect similar conditions on Mars compared to Earth, maybe a bit more acidic in general.

Our recent study shows that being successful in the search for life in clays on Mars will depend on the characteristics of the fluids that have been interacting with those clays in the past: alkaline fluids will not hamper the capability of clays to host organics. Our work shows where we should focus the search for life on Mars: in places where

no interaction with acidic fluids is recorded in the geological record.

For example, Perseverance got it right from the beginning by going to Jezero crater, which is one of the few spots on Mars where carbonates are abundant. Carbonates are evidence that acidic fluids have not been pervasive since their deposition.



Dr Alberto G. Fairén is a staff research scientist at the Centro de Astrobiología, Madrid, Spain



© Adrian Mann

Left: Although Mars rovers have found hints of ancient alien life, there have been no solid detections

Right: Galaxy cluster Abell 520 in a false-colour image in order to emphasise dark matter

Did you know?

Although the Red Planet is just half the diameter of Earth, it has the same amount of dry land.

COSMOLOGY

Where are the best spots to study dark matter?

The most promising places to look at are galaxies and galaxy clusters. In a paper that recently appeared in *Nature*, a team of scientists showed that if dark matter is made of weakly interacting massive particles, then a very rich population of dark halos should exist. The way that dark matter is distributed in the smallest clumps should be very similar to how it is distributed in the largest clumps. For this reason we say that the density profile of dark matter halos should be universal. If dark matter is made of different kinds of particles, the picture would change completely. In such scenarios the smallest clumps could not form, or the density profiles of dark matter in galaxies and galaxy clusters would be very different from the universal profile.

We should try to figure out how dark matter is distributed in galaxies and galaxy clusters in order to understand what it is made of. We do that through gravitational lensing! Any mass in the universe bends light from distant sources, causing noticeable distortions on their images. These effects can be reversed to learn how the dark matter is distributed in galaxies and galaxy clusters.

Dr Massimo Meneghetti is an adjunct professor at the National Institute for Astrophysics (INAF), Italy



ASTROPHYSICS

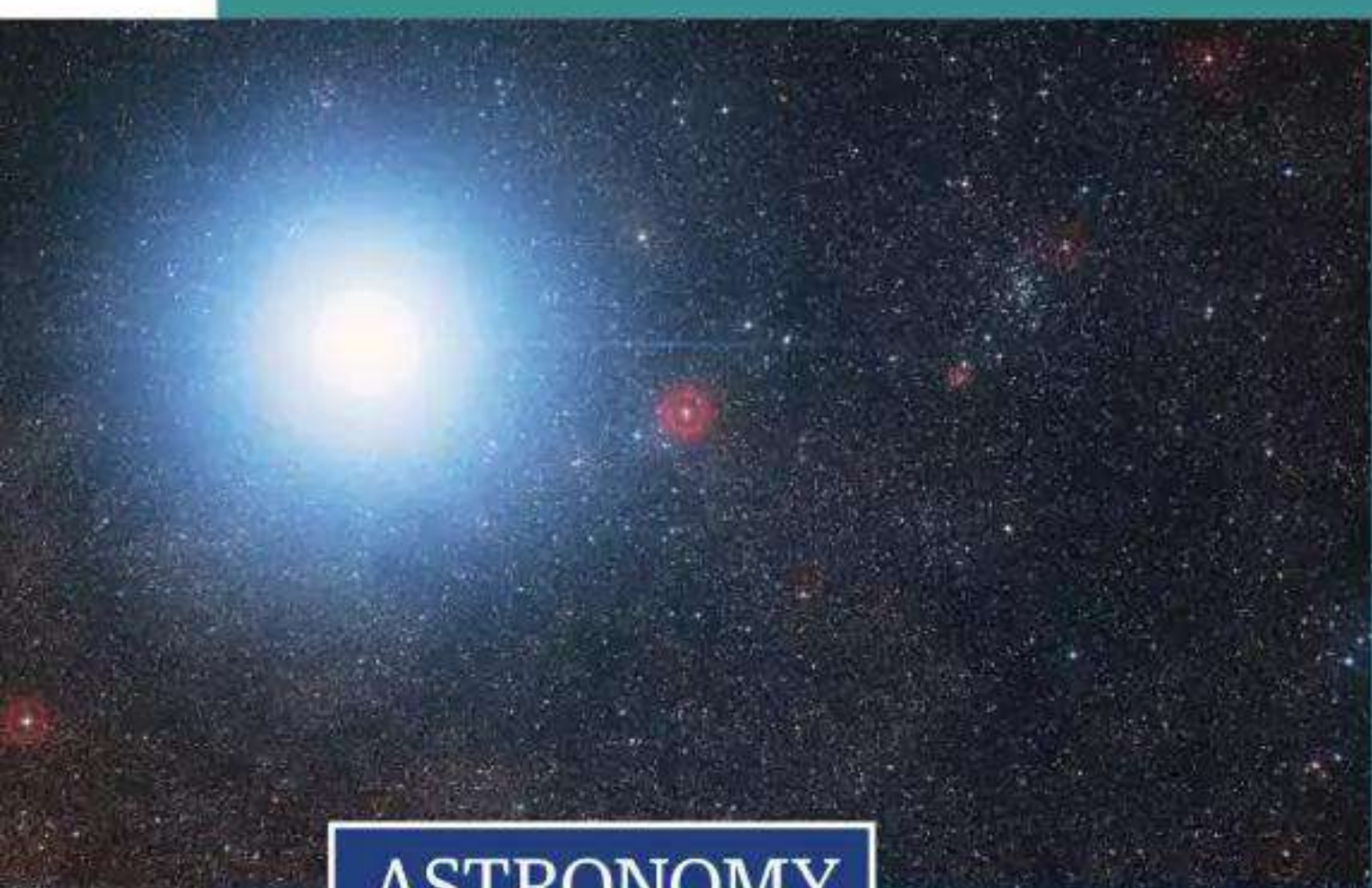
How did the Milky Way get the Magellanic Cloud dwarf galaxies?

Based on measurements of their velocities across the sky, the Magellanic Clouds are inferred to be on their first passage past the Milky Way. This means they are relative newcomers to our galaxy, having spent most of their lives over half a million light years away. Furthermore, the Magellanic Clouds are accompanied by their own very faint satellite galaxies, and so are thought to be the two largest members of a group of galaxies known as the Magellanic Group. It's as if they approached the Milky Way with a coterie of attendants. As the clouds fell in, tidal forces and gas pressure stripped out a massive tail of gas, the Magellanic Stream, in an extended wake behind them. Like a galactic vapour trail covering almost half the entire sky and glowing in radio light, this stream stands as a visible reminder to the past orbits of these clouds.



Dr Andrew Fox is an astronomer at the Space Telescope Science Institute (STScI), Maryland

Above: The Large and Small Magellanic Clouds are visible in the top right of the image



© Digitized Sky Survey 2

ASTRONOMY

What would it look like if Alpha Centauri went supernova?

Alpha Centauri is a triple-star system with two Sun-like, low-mass stars, A and B, orbiting each other and a red dwarf star, C, orbiting farther out. A and B are not close enough to interact with each other, necessary for a low-mass star to explode as a thermonuclear supernova.

If a supernova was triggered at the Alpha Centauri system, it would be quite a display, but also deadly for observers on Earth. The light, including the harmful radiation, would take four years to reach Earth. When it arrived it would be noticeable right away, lighting up the sky at night and competing with the Sun during the day.

A large amount of high-energy radiation would disintegrate the ozone in our atmosphere, allowing the harmful ultraviolet radiation from the Sun and the supernova to enter. This would trigger a mass-extinction event. If we were lucky enough to survive this, we would witness the supernova brighten gradually over a couple of weeks to a peak brightness that is 10,000-times brighter than the full Moon before it gradually fades away over years. The colour of the supernova will oscillate between a red and blue tinge over a time scale of weeks.

Dr Eric Hsiao is an assistant professor in the department



of physics at Florida State University

Left: This is the current view of the Alpha Centauri system from Earth

Right: The Murchison Widefield Array (MWA) searches for alien signals in Western Australia

HUNT FOR LIFE

What signals are astronomers looking out for when searching for signs of alien intelligence and technology?

In the decades since we began exploring the cosmos through radio astronomy, we've only found one signal that couldn't be explained through our current understanding of the way stars, galaxies and dust clouds in space give off light. It's hard to know what to look for when we're searching for something entirely new. For example, how would you find your car keys if you'd never seen them before? Maybe you have an idea of what you were looking for based on some expectation. Similarly, we create models using our best guess of what we think a signal from sentient life might look like and base the searches with radio telescopes on this. In particular we are looking for small changes in the intensity in waves of light.

Other objects in space can create signals that are similar to the ones we're looking for, which makes this even harder. If it exists, we expect a signal caused by an alien civilisation to be narrower than



© Pete Wheeler / ICRAR

those generated by the natural universe. Even though we are looking for light, you can think of this as the difference of the sound made by an electric piano versus the more 'full-bodied' sound of an organ. In nature we would expect our signals to be like an organ and a signal sent by an alien civilisation to be closer to the 'tink' of a toy piano.

Dr Chenoa Tremblay is a postdoctoral fellow at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia



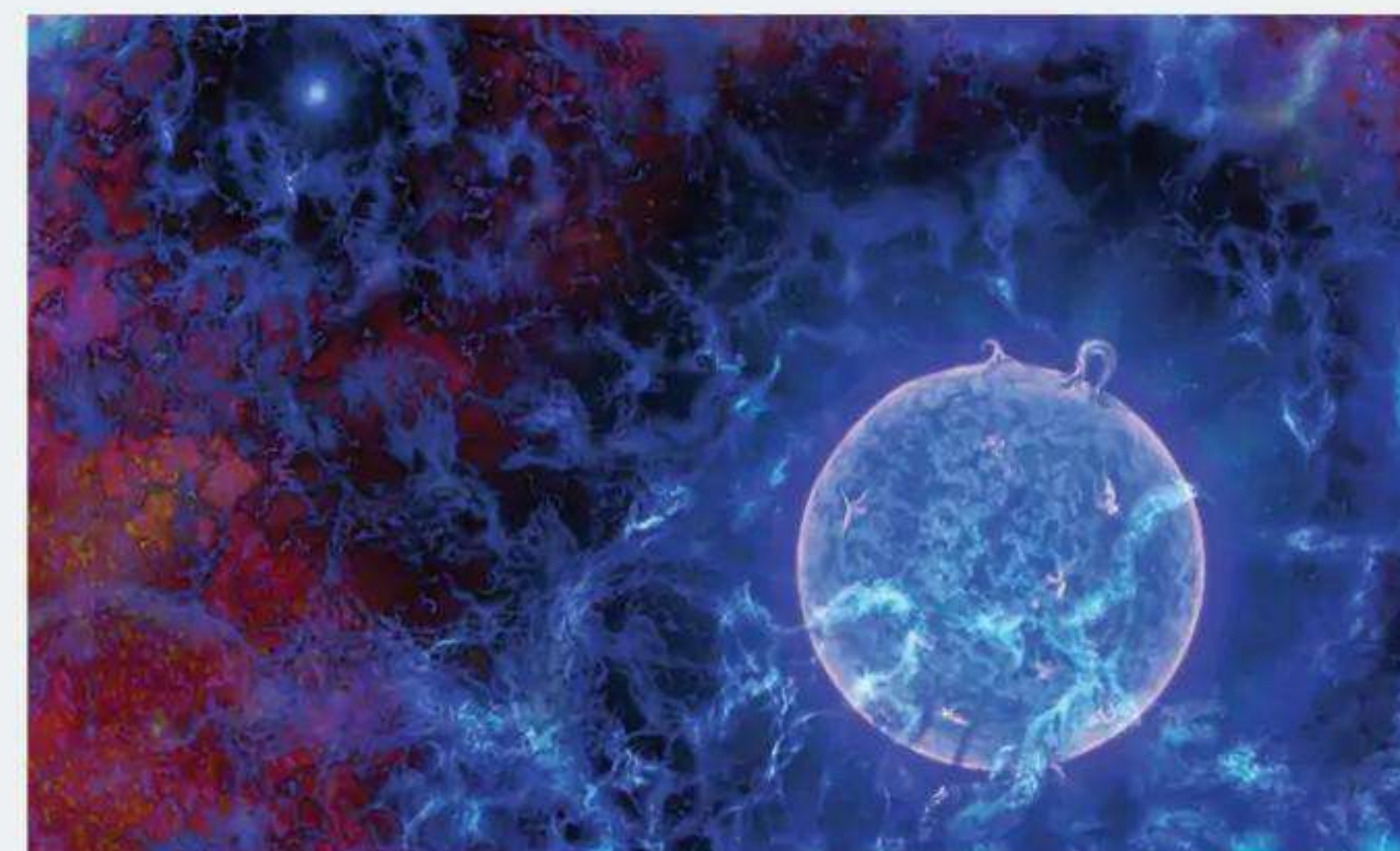
COSMOLOGY

How long did the first stars in the universe live for?

You can tell a lot about a star based only on its size and mass, because that is what will ultimately determine the energy source of the star and therefore its eventual death. At the heart of every star is a fusion core where it's incredibly dense and the temperatures are hot enough for two atoms to fuse into a new element and generate light. This is why stars glow and planets don't.

Stars up to eight times the mass of our Sun have hydrogen fusion that eventually runs out and becomes helium fusion. At this point the star swells to become a red giant and will die as either a Type Ia supernova or as a white dwarf at an age of about 0.5 to 3 billion years old. Stars that are eight to 40 times the mass of our Sun have layers of fusion shells within them, like an onion, meaning they are bright and explosive. These stars only live a few million years and die as either a supernova, pulsar or a black hole.

Finally, stars that are more than 100 times the Sun's mass, which only existed at the beginning of



© N.R. Fuller/National Science Foundation

the universe, were so large that they were unstable and only lived for tens to hundreds of thousands of years. However, it was in the interiors of these first stars that elements heavier than hydrogen and helium were created, such that every subsequent generation of stars could build off these new elements to eventually create most of the elements in the periodic table.



Dr Natalie Hinkel is a senior research scientist at Southwest Research Institute, San Antonio, Texas

Did you know?

Gold has 79 protons and 118 neutrons. It's a good conductor of electricity and heat, but due to its rarity is valued more as jewellery.

ASTROPHYSICS

How are gold, silver and bronze created in the universe?

Copper, which is the primary component of bronze, is created during supernova explosions at the end of the lives of massive stars, using existing nitrogen as a seed. In astronomy, elements heavier than helium are called 'metals', including nitrogen. It becomes harder to form copper in 'metal-poor' stars that were born much earlier than the Solar System.

Silver is heavier than copper, and contains more neutrons relative to the number of protons in its nucleus. Therefore silver should be created by an extra process, called 'neutron capture', during supernova explosions. Gold atoms are much heavier and harder to make than silver and copper, and can be made through two different astronomical events. The first one is a neutron star merger; a neutron star is a high-density star made of neutrons. If two such stars collide with each other, it is possible to form very neutron-

rich elements such as gold. The neutron star merger was observed with gravitational waves in 2017.

In our recent study, we found that this mechanism alone is not enough to account for all the gold seen in the universe. Another production site of gold is rare spinning massive stars which cause jet explosions powered by magnetic fields. We also found, however, that even including both these production sites it is still not possible to explain the observed amount of gold. To solve this mystery, we need more nuclear experiments, astronomical observations of metal-poor stars and computer simulations of stars and supernovae.

Dr Chiaki Kobayashi is a reader in astrophysics for the Centre for Astrophysics Research, University of Hertfordshire, UK



Above: A neutron star merger is just one source of gold creation

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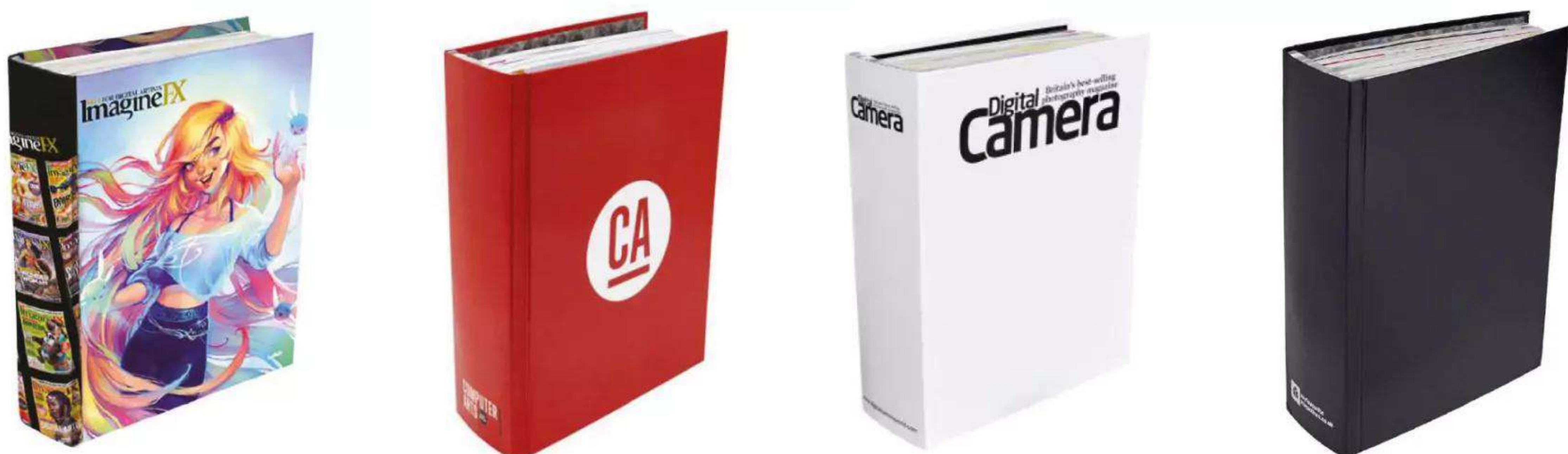
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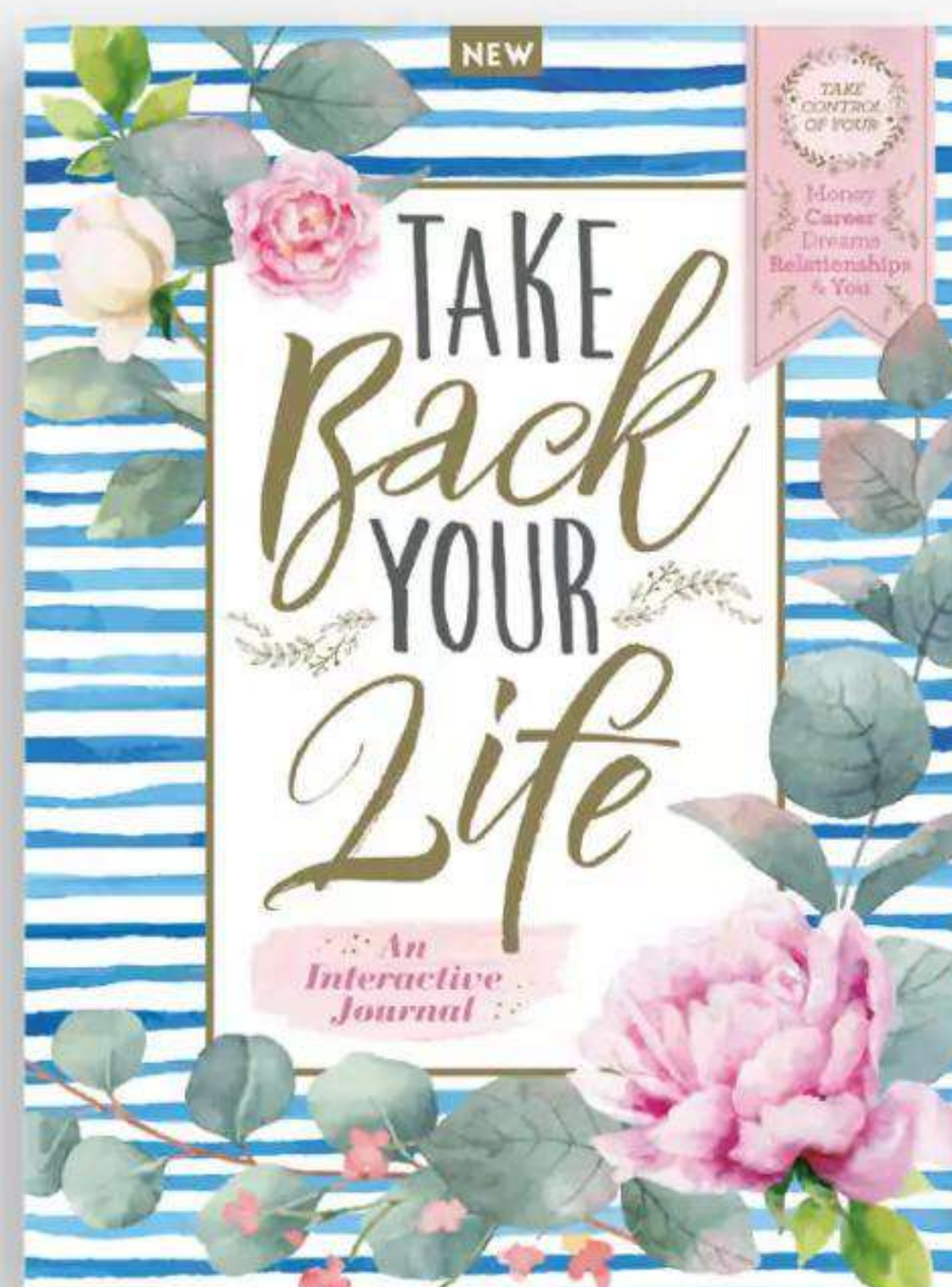
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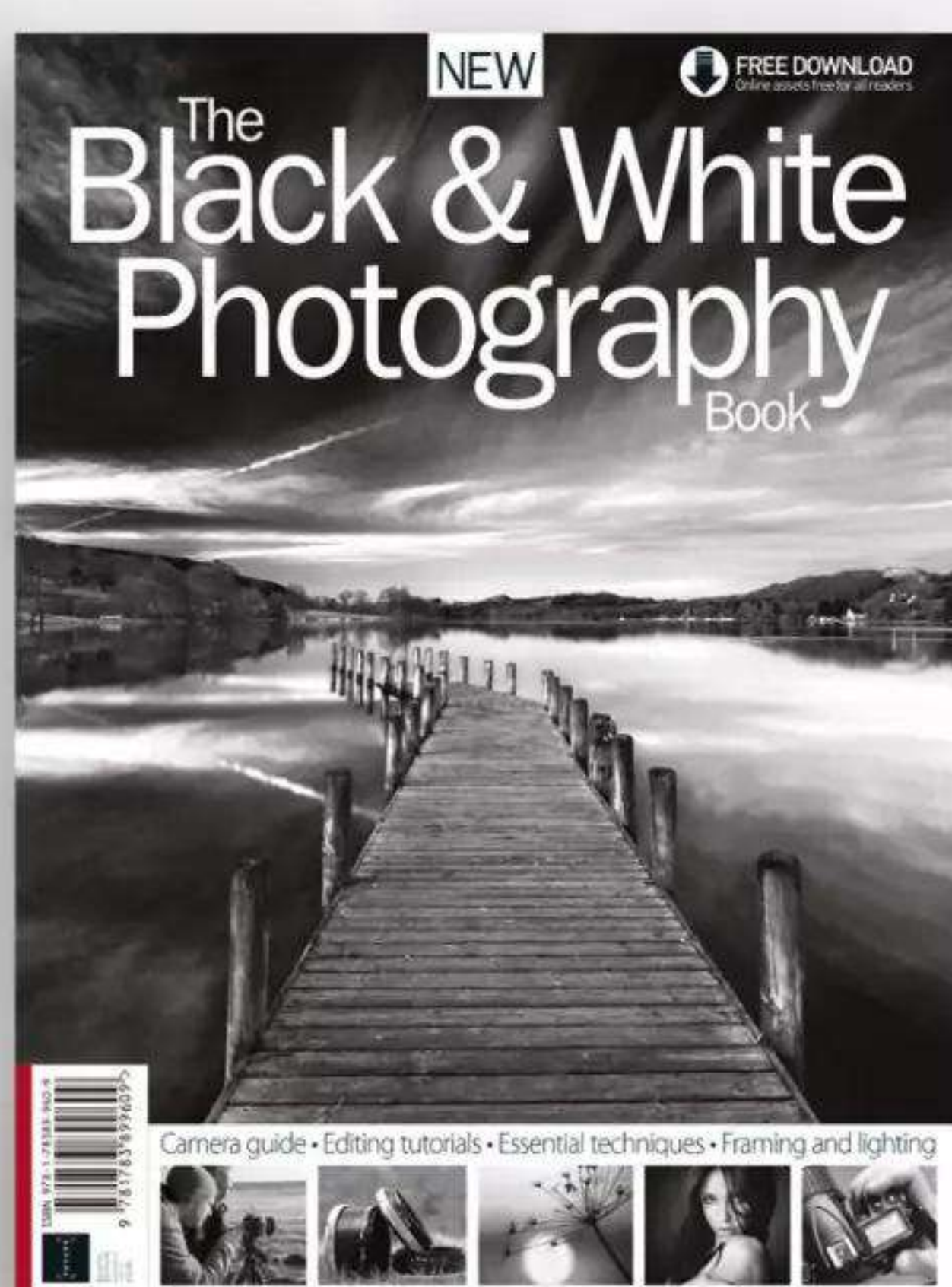
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STARGAZER

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What's in the sky?

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JOHN

MOON
PR



**8
NOV**



Mercury is at half phase in the dawn sky

© ESO

**9
NOV**



Mercury reaches its highest point in the dawn sky, dazzling at magnitude -0.6

**15
NOV**



Conjunction between Jupiter and the dwarf planet Pluto in Sagittarius

**17
NOV**



The Leonids reach their peak of 15 meteors per hour

**17
NOV**



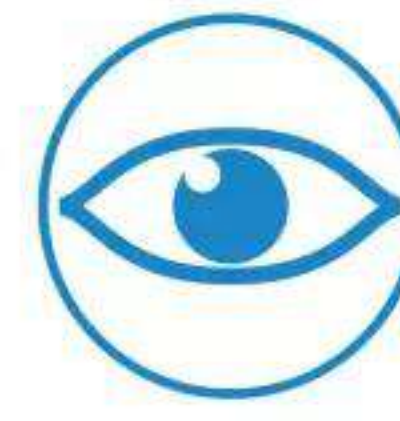
The Pleiades open star cluster (M45) is well placed for observation in Taurus

**19
NOV**



The Moon and Saturn make a close approach, passing within 2°28' of each other in Sagittarius

**28
NOV**



The Orionids reach their peak of three meteors per hour



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In order to preserve your night vision, you should read our observing guide under red light

10 NOV



Mercury is at its greatest distance from the Sun in the dawn sky

12 NOV



The Northern Taurids reach their peak of five meteors per hour

12 NOV



The Moon and Venus make a close approach, passing within 2°46' of each other in Virgo



Source: Wikipedia Commons
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19 NOV



The Moon and Saturn make a close approach, passing within 2°50' of each other in Sagittarius



© NASA/ESA

21 NOV



The Alpha Monocerotids reach their peak

25 NOV



The Moon and Mars pass within 4°27' of each other in Cetus and Pisces

30 NOV



Penumbra lunar eclipse visible from Oceania, the Americas, eastern Asia and northern Europe



Naked eye



Binoculars



Small telescope



Medium telescope



Large telescope



Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Opposition

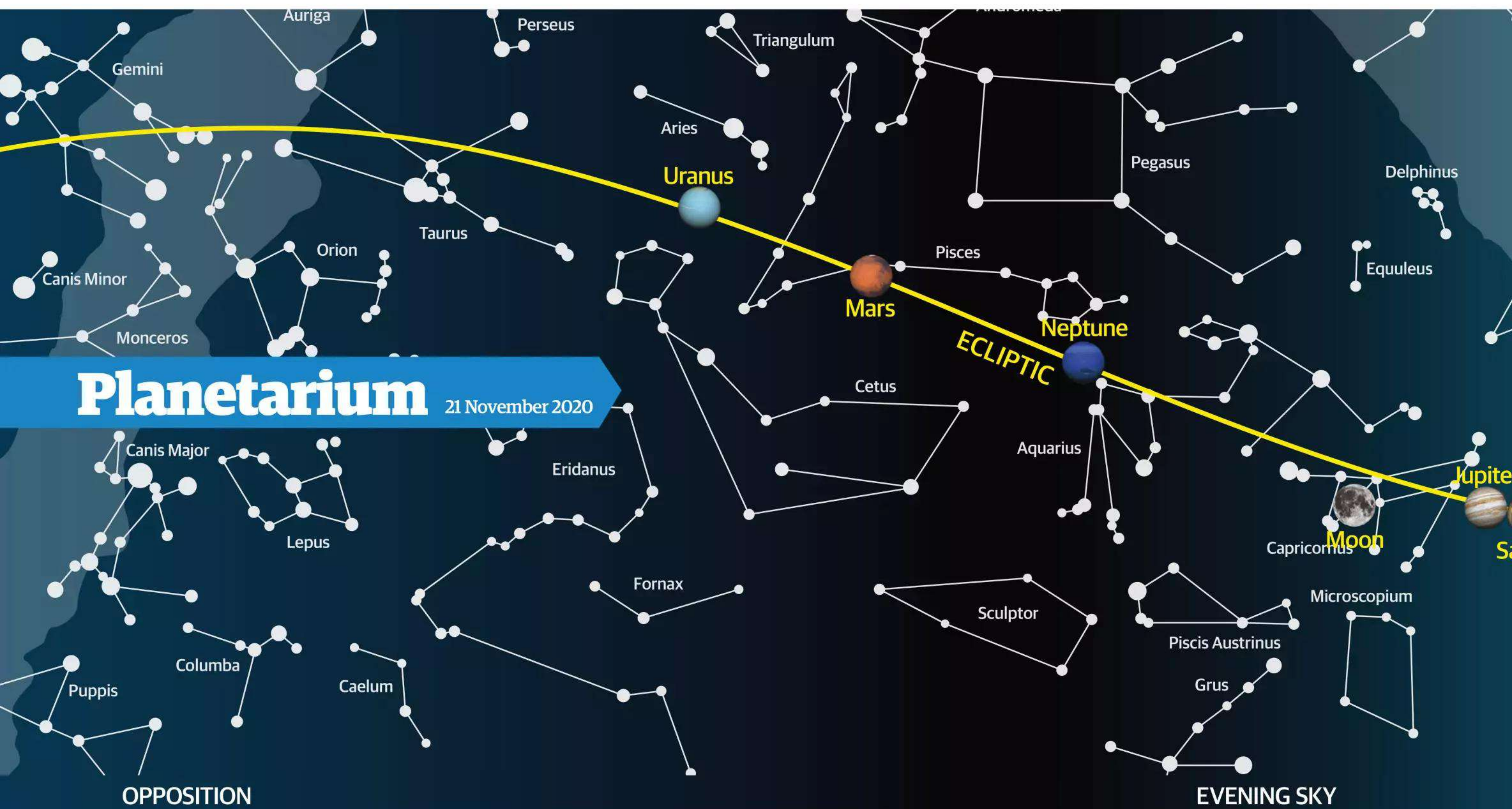
When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.



Moon calendar

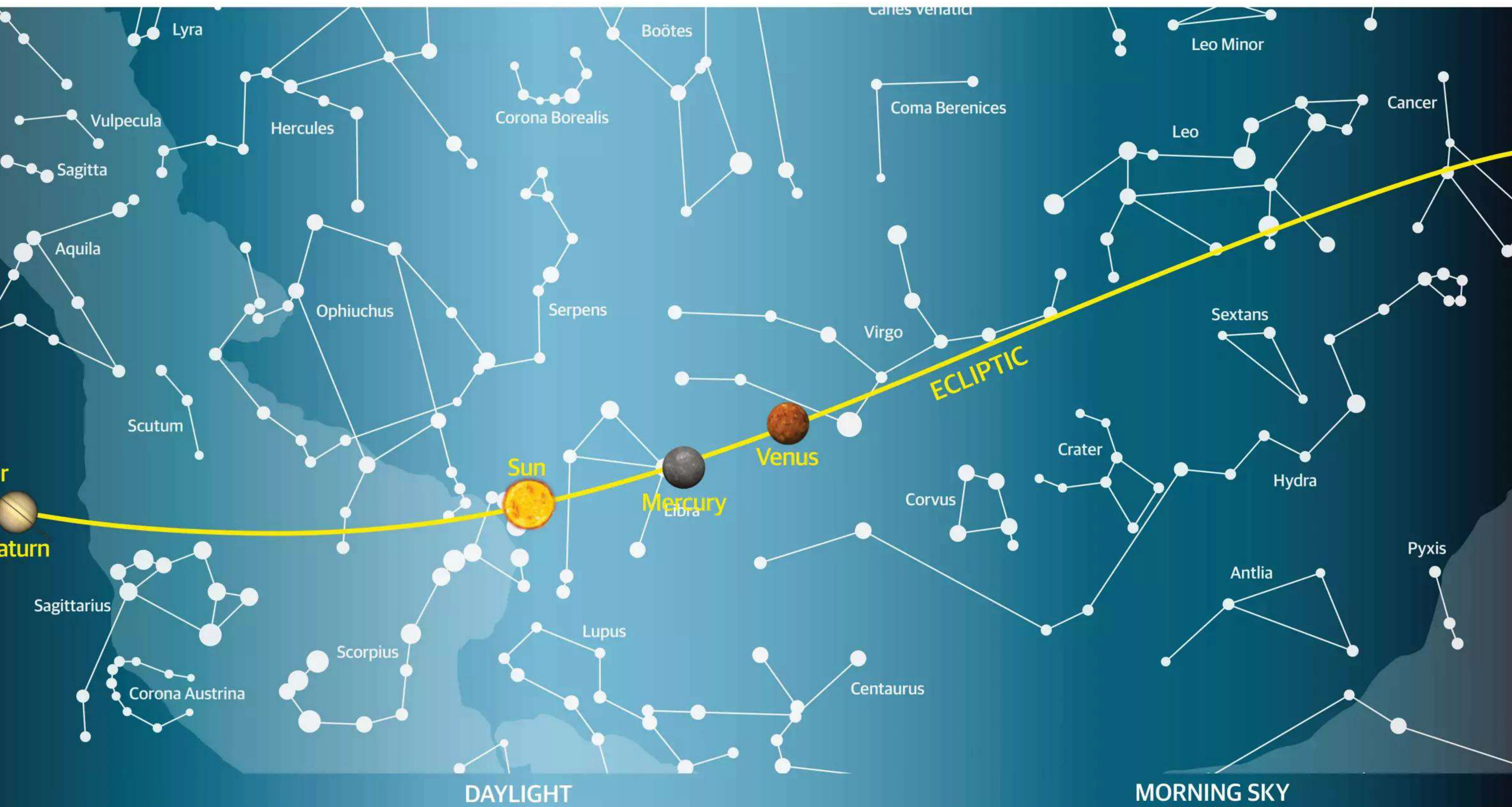
* The Moon does not pass the meridian on 30 November

5 NOV 82.5% ☾ 11:52 ☀ 19:26	6 NOV 74.0% ☾ 12:43 ☀ 20:24	7 NOV 64.3% ☾ 13:24 ☀ 21:33	8 NOV TQ 53.6% ☾ 13:57 ☀ 22:49
9 NOV 42.5% ☾ 14:23 ☾ ---	10 NOV 31.3% ☾ 00:09 ☀ 14:46	11 NOV 20.9% ☾ 01:32 ☀ 15:05	12 NOV 11.8% ☾ 02:57 ☀ 15:24
13 NOV 5.0% ☾ 04:23 ☀ 15:44	14 NOV 0.9% ☾ 05:52 ☀ 16:06	15 NOV NM 0.2% ☾ 07:23 ☀ 16:33	
16 NOV 2.6% ☾ 08:51 ☀ 17:08	17 NOV 8.0% ☾ 10:13 ☀ 17:54	18 NOV 15.7% ☾ 11:21 ☀ 18:52	19 NOV 25.0% ☾ 12:14 ☀ 20:00
20 NOV 35.1% ☾ 12:52 ☀ 21:13	21 NOV 45.6% ☾ 13:21 ☀ 22:27	22 NOV FQ 55.8% ☾ 13:43 ☀ 23:39	
23 NOV 65.6% ☾ 14:01 ☾ ---	24 NOV 74.6% ☾ 00:49 ☀ 14:16	25 NOV 82.5% ☾ 01:57 ☀ 14:31	26 NOV 89.2% ☾ 03:04 ☀ 14:45
27 NOV 94.5% ☾ 04:11 ☀ 15:00	28 NOV 98.1% ☾ 05:19 ☀ 15:17	29 NOV 99.8% ☾ 06:28 ☀ 15:38	
30 NOV FM ---%* ☾ 07:37 ☀ 16:04	1 DEC 99.6% ☾ 08:45 ☀ 16:38	2 DEC 97.4% ☾ 09:47 ☀ 17:22	3 DEC 93.2% ☾ 10:42 ☀ 18:17

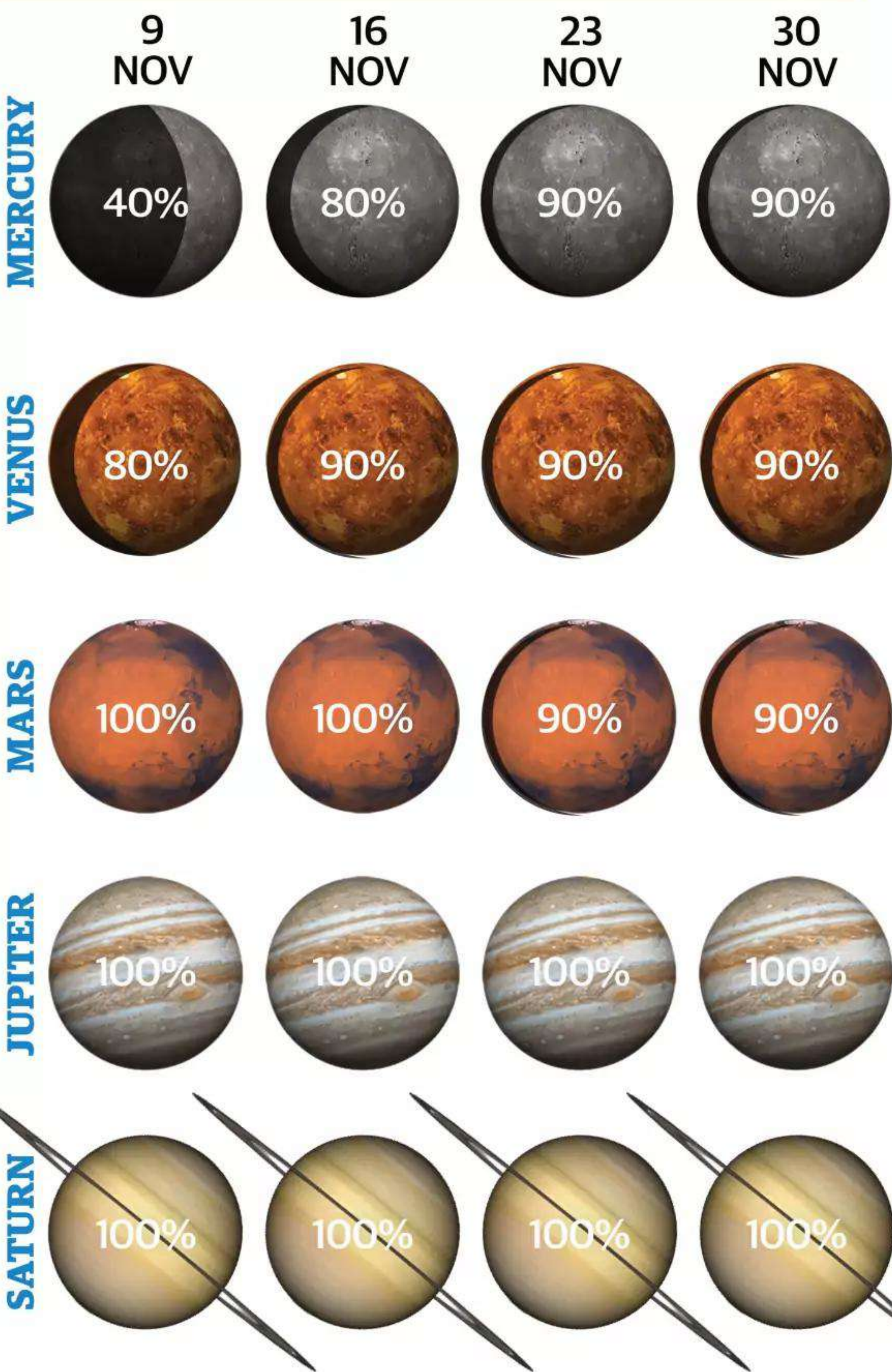
% Illumination
☾ Moonrise time
☾ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



Planet positions

All rise and set times are given in GMT

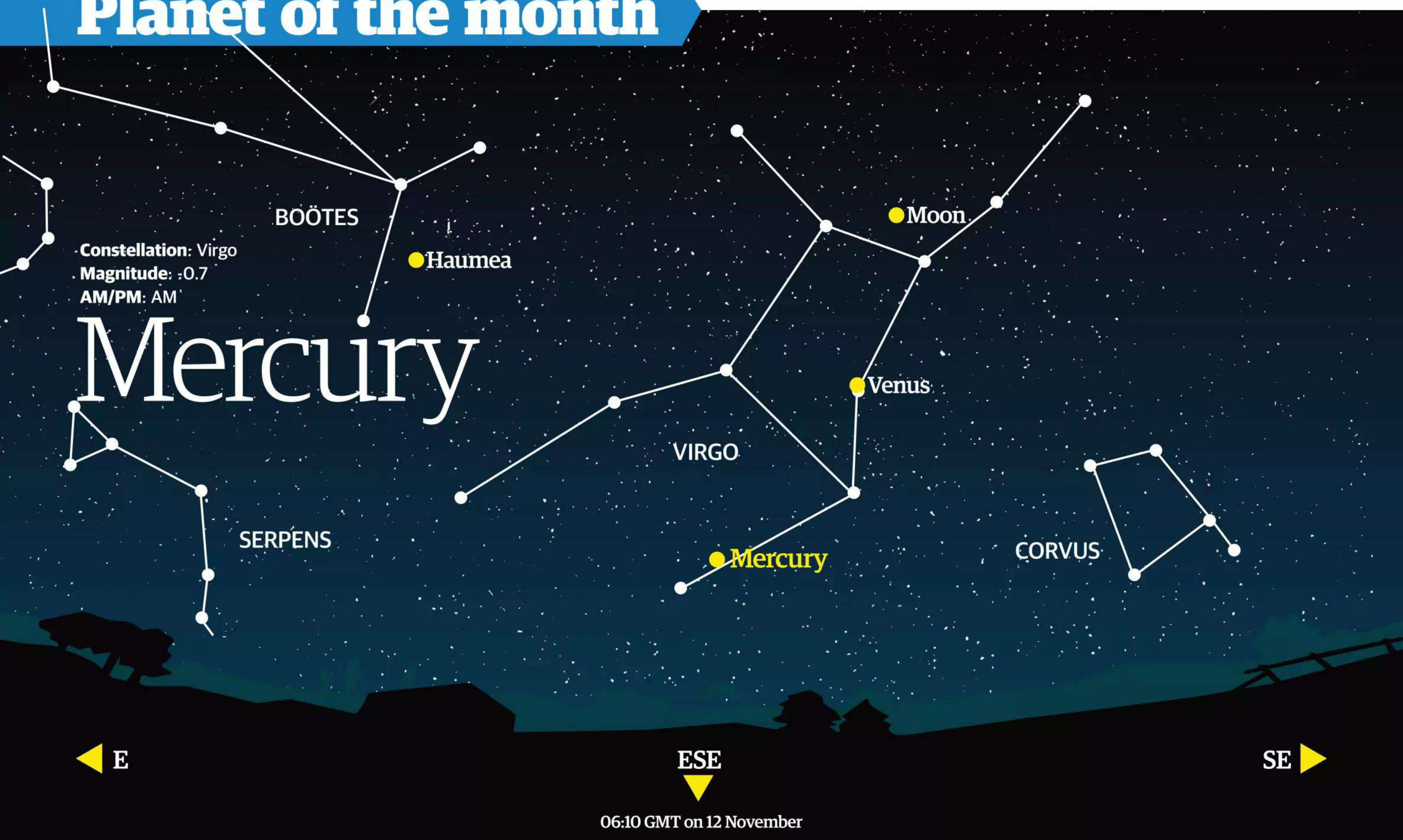
	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	7 NOV	13h 41m 37s	-08° 15' 33"	Virgo	-0.3	05:13	15:56
	14 NOV	14h 07m 15s	-10° 30' 52"	Virgo	-0.7	05:23	15:42
	21 NOV	14h 44m 30s	-14° 09' 05"	Libra	-0.7	05:52	15:32
	28 NOV	15h 26m 29s	-17° 49' 57"	Libra	-0.7	06:28	15:25
	2 DEC	15h 51m 38s	-19° 43' 12"	Libra	-0.8	06:49	15:23
VENUS	7 NOV	12h 46m 07s	-03° 05' 28"	Virgo	-4.0	03:51	15:27
	14 NOV	13h 18m 02s	-06° 19' 28"	Virgo	-4.0	04:12	15:15
	21 NOV	13h 50m 29s	-09° 28' 37"	Virgo	-4.0	04:33	15:04
	28 NOV	14h 23m 37s	-12° 28' 25"	Libra	-4.0	04:54	14:53
	2 DEC	14h 42m 55s	-14° 05' 15"	Libra	-4.0	05:07	14:48
MARS	7 NOV	00h 58m 21s	+04° 46' 42"	Pisces	-1.9	15:22	04:21
	14 NOV	00h 56m 27s	+05° 03' 11"	Pisces	-1.7	14:51	03:53
	21 NOV	00h 57m 02s	+05° 32' 07"	Pisces	-1.5	14:21	03:29
	28 NOV	00h 59m 58s	+06° 12' 22"	Pisces	-1.2	13:53	03:07
	2 DEC	01h 02m 35s	+06° 39' 47"	Pisces	-1.1	13:38	02:57
JUPITER	7 NOV	19h 33m 51s	-22° 08' 31"	Sagittarius	-2.2	12:24	20:27
	14 NOV	19h 38m 38s	-21° 57' 48"	Sagittarius	-2.1	12:00	20:06
	21 NOV	19h 43m 48s	-21° 45' 36"	Sagittarius	-2.1	11:37	19:45
	28 NOV	19h 49m 19s	-21° 31' 56"	Sagittarius	-2.1	11:13	19:24
	2 DEC	19h 52m 36s	-21° 23' 27"	Sagittarius	-2.0	11:00	19:13
SATURN	7 NOV	19h 53m 25s	-21° 13' 47"	Sagittarius	+0.6	12:38	20:53
	14 NOV	19h 55m 22s	-21° 08' 48"	Sagittarius	+0.6	12:12	20:28
	21 NOV	19h 57m 36s	-21° 02' 59"	Sagittarius	+0.6	11:46	20:03
	28 NOV	20h 00m 04s	-20° 56' 22"	Sagittarius	+0.6	11:20	19:39
	2 DEC	20h 01m 34s	-20° 52' 15"	Sagittarius	+0.6	11:05	19:25



This month's planets

Fleeting planet Mercury is at prime viewing in the morning sky alongside dazzling Venus

Planet of the month



If you've never seen Mercury - and there are plenty of astronomers, even experienced ones, who haven't - November is your chance! The closest planet to the Sun moves out to greatest western elongation - when it appears at its greatest distance to the west of the Sun - on the morning of 10 November. Throughout the beginning of November it improves in brightness and visibility in the predawn sky. On the morning of 10 November Mercury will be 11 degrees above the horizon in the darker skies at 06:30 before reaching 15 degrees by 07:10, just before sunrise.

Mercury will be bright enough to be seen with the naked eye - you just need to know where to look - just south of Venus. If you are using

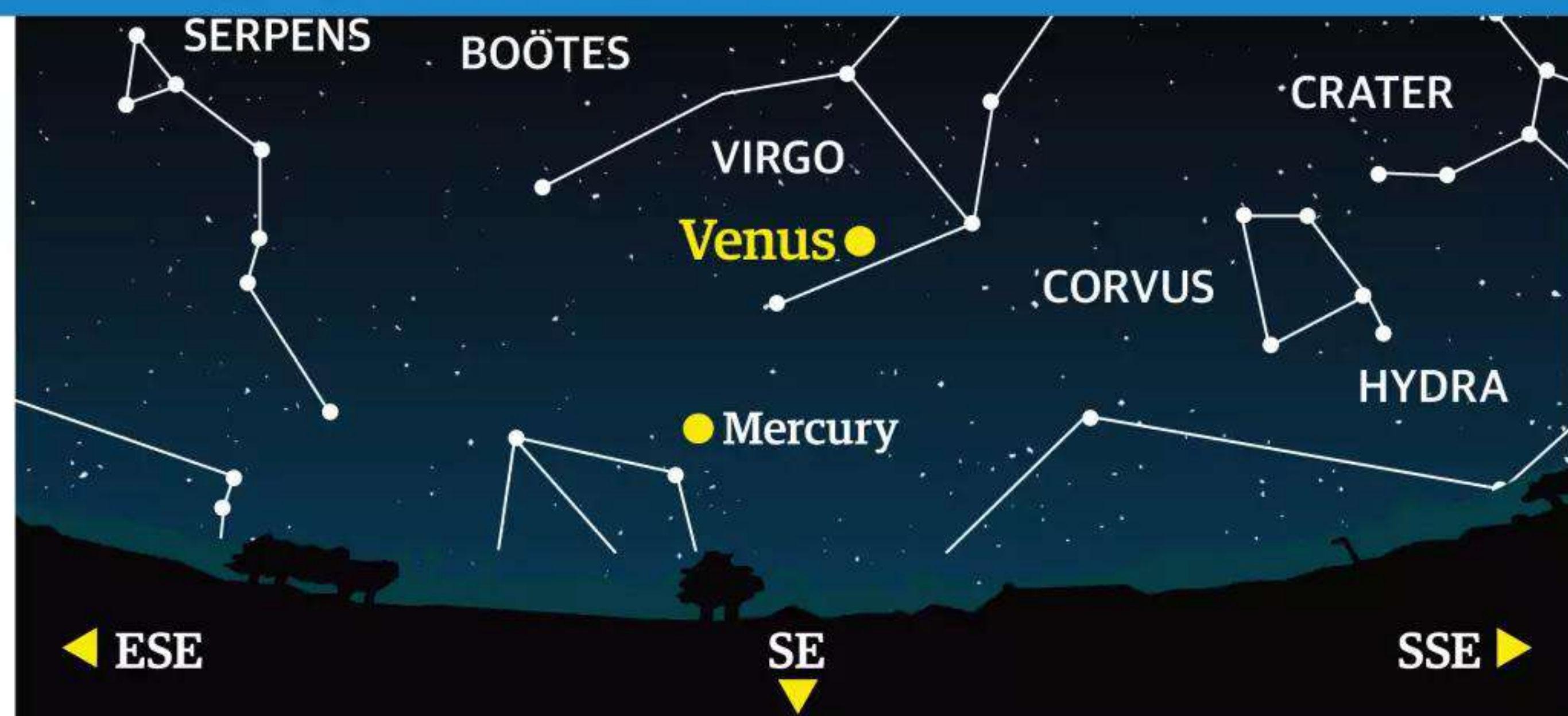
binoculars or a telescope, it is important that you remember never to search for Mercury or any other planet or star close to the Sun when the Sun is above the horizon. Looking at the Sun through these optical instruments, even if just accidentally, will damage your eyesight and could lead to permanent blindness. Even if you think the Sun is just below the horizon, don't risk it.

Mercury is visible throughout most of the month, but its altitude before sunrise decreases until by the end of the month it's too close to the Sun to be seen.

The European Space Agency (ESA) and the Japan Aerospace Exploration Agency's (JAXA) BepiColombo spacecraft is currently on its way to study Mercury, due to arrive there in 2025.

"THROUGHOUT THE BEGINNING OF NOVEMBER IT IMPROVES IN BRIGHTNESS AND VISIBILITY IN THE PREDAWN SKY"

Venus 07:00 GMT on 20 November



Constellation: Virgo

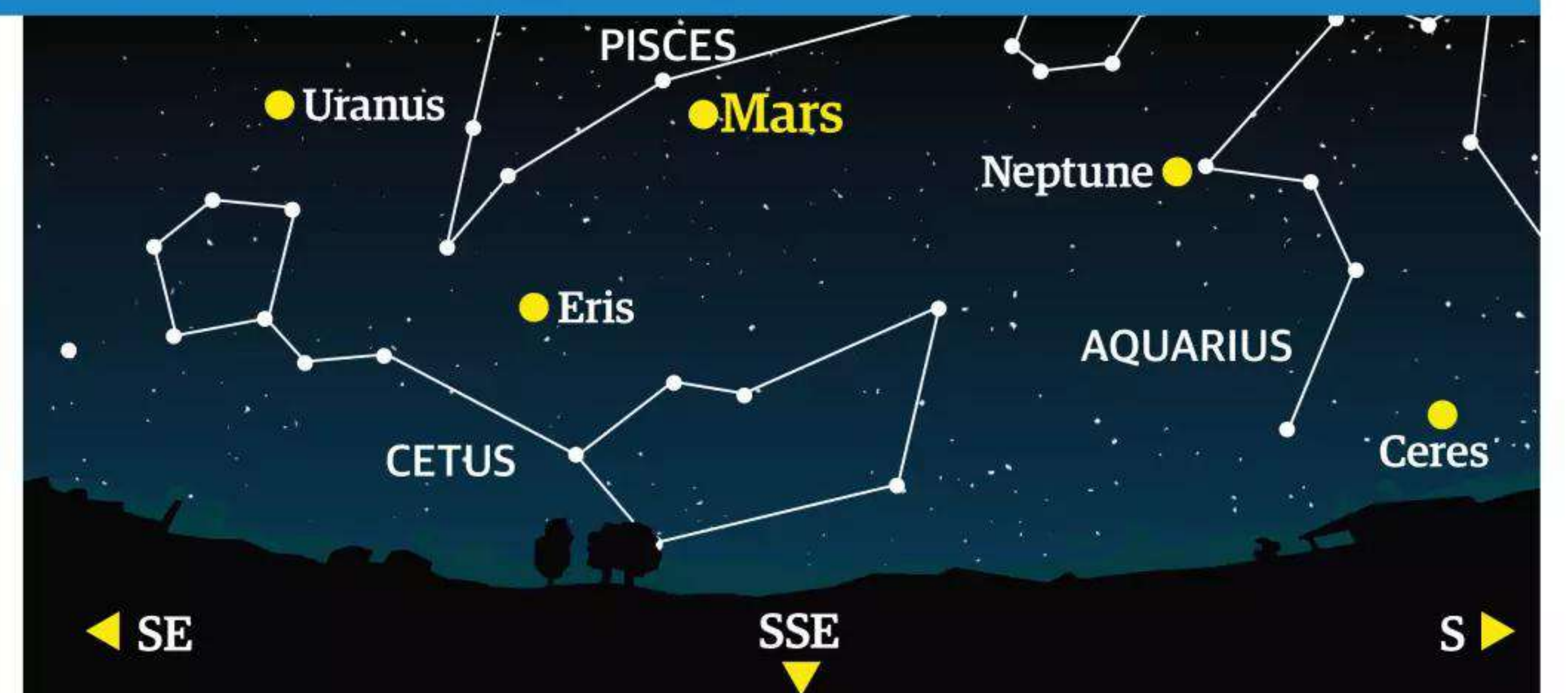
Magnitude: -4.0

AM/PM: AM

Venus is a brilliant 'morning star' throughout November and into December, the brightest object in

the sky other than the Moon and the Sun. Rising several hours before the Sun, its altitude decreases as the month progresses and we move into December, but is still above ten degrees before the Sun rises.

Mars 19:00 GMT on 20 November



Constellation: Pisces

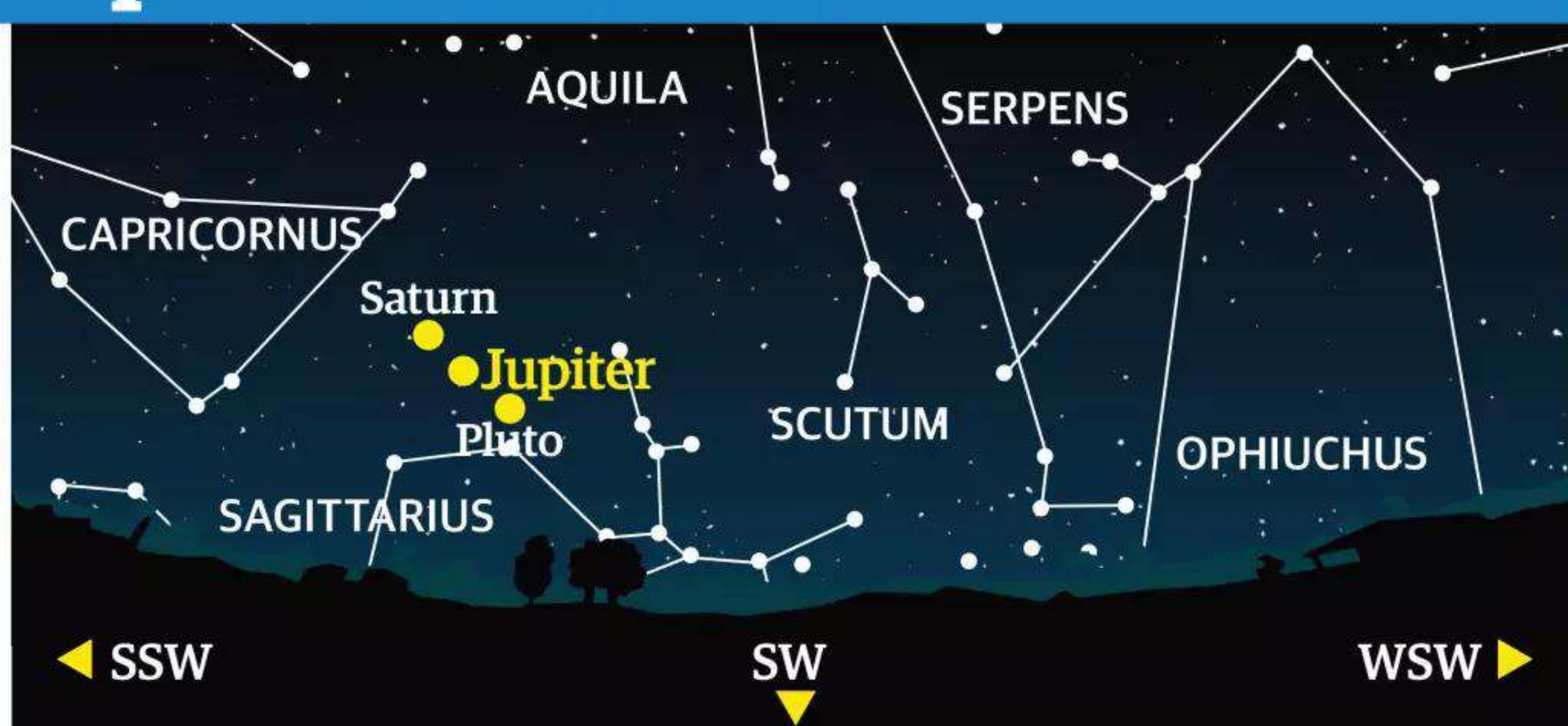
Magnitude: -1.5

AM/PM: AM/PM

Given that Mars was at opposition in October, the Red Planet still shines brightly, although it does fade

between the beginning of November and the beginning of December, and its disc will shrink from 20 arcseconds to 14 arcseconds. If you've not taken a good look at Mars yet this year, now is the time.

Jupiter 17:00 GMT on 2 December



Constellation: Sagittarius

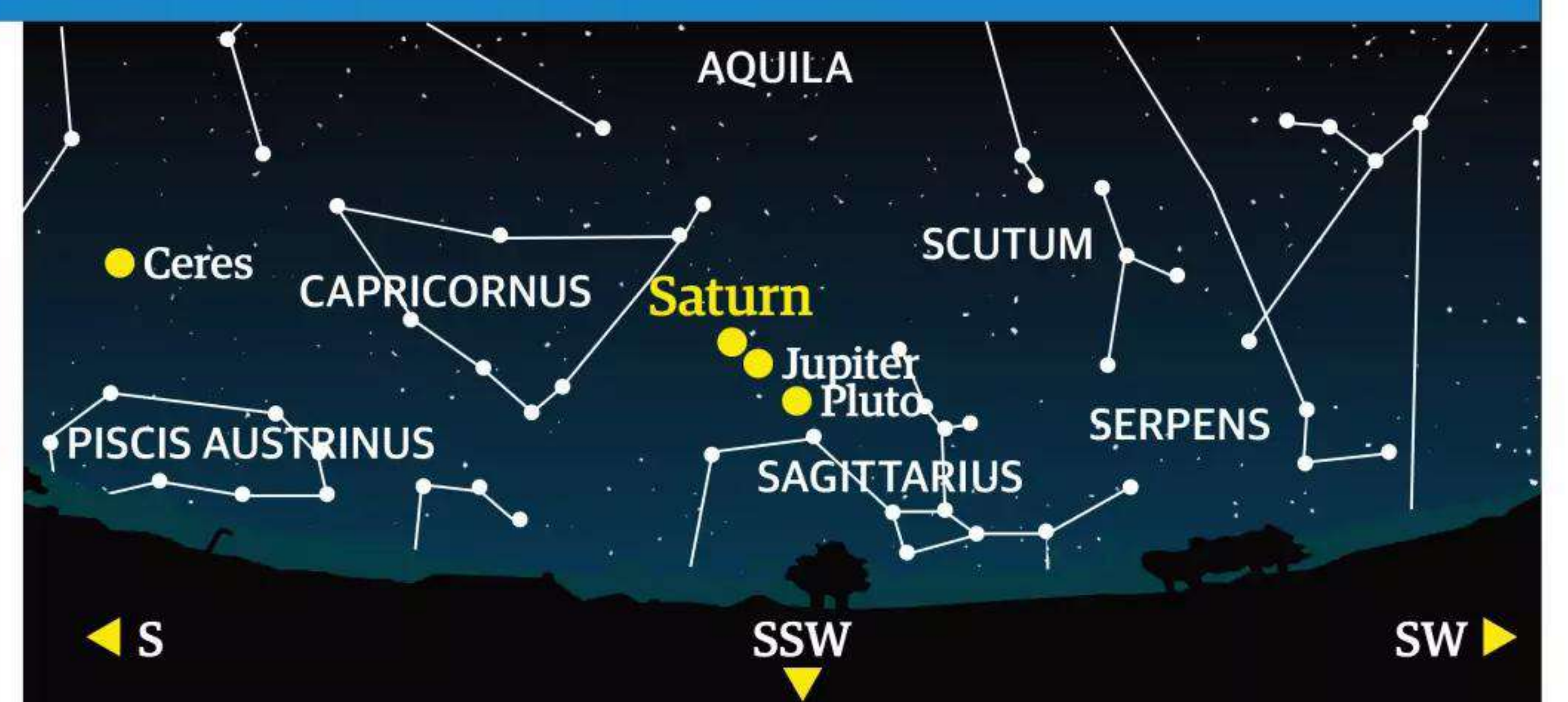
Magnitude: -2.1

AM/PM: PM

The largest planet in the Solar System is a pale shadow of its summertime splendour. Lurking

low in the southwest after sunset, it is best seen in the first half of November. If you do manage to spot it you will see it shining brighter than anything else in that part of the sky until it sets.

Saturn 17:00 GMT on 30 November



Constellation: Sagittarius

Magnitude: +0.6

AM/PM: PM

The ringed planet has followed Jupiter across the sky all year, and like Jupiter it now lingers low in the

southwest after sunset. You will need to use a telescope to see its famous rings. At the beginning of the month Saturn sets at around 21:00, but by the beginning of December it sets as early as 19:45.

Uranus 18:00 GMT on 1 December



Constellation: Aries

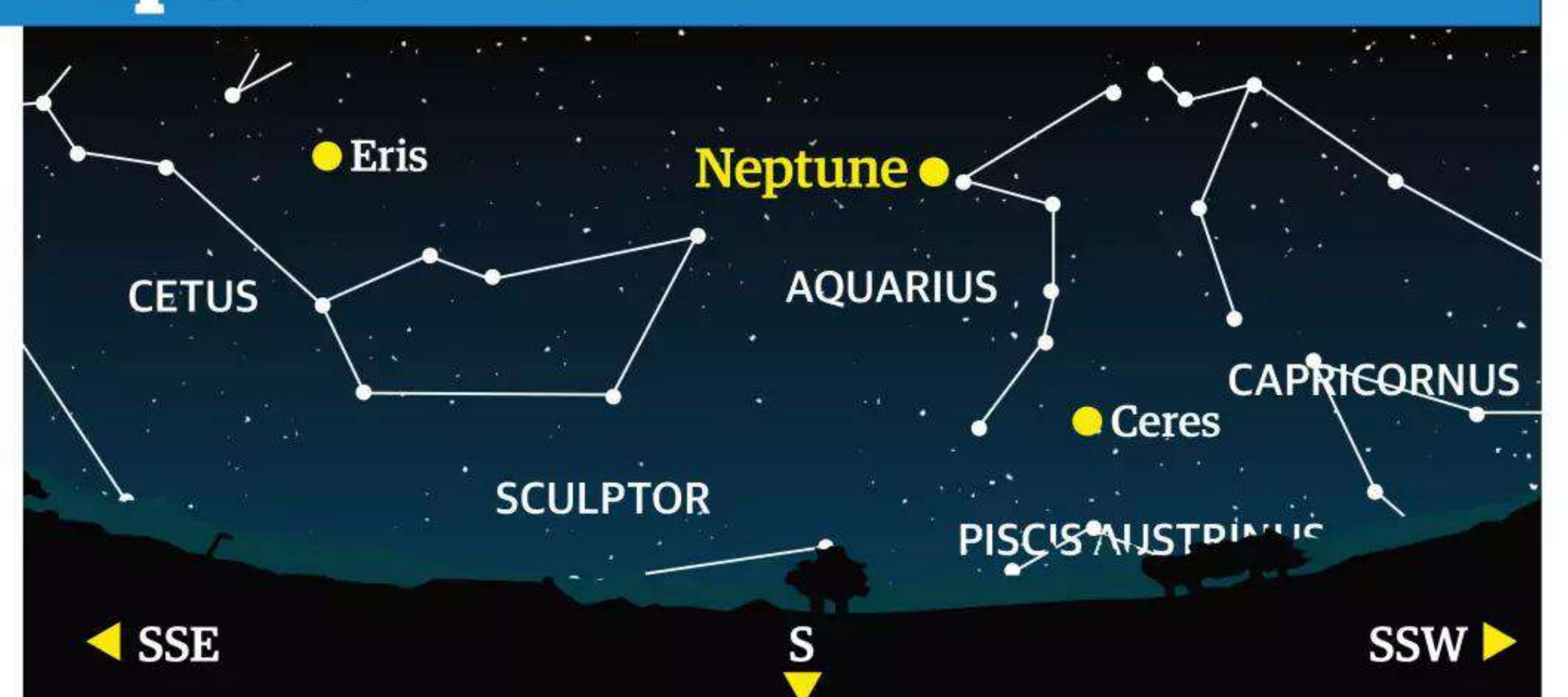
Magnitude: +5.7

AM/PM: AM/PM

Although it's only a binocular or telescopic object due to its vast distance from us - on average

around 2.8 billion kilometres (1.7 miles) away - the ice giant Uranus is still a good target to view all night. Binoculars will help you find it, while a four- to six-inch telescope should show its turquoise disc.

Neptune 19:00 GMT on 2 December



Constellation: Aquarius

Magnitude: +7.9

AM/PM: PM

Fainter and farther out than Uranus, Neptune is still visible all evening, setting by about 01:00. Like Uranus,

binoculars will find it, but you'll need a four- to six-inch telescope to see it as a small, bluish disc. For beginners, a Go-To-mounted telescope is highly recommended for finding Neptune.



Top tip!

We can see Mare Orientale sometimes when the wobbling, or 'libration', of the Moon briefly tilts it towards us.

Moon tour

The far side of the Moon

What wonders can be found on the mysterious side of the Moon which we can never see?

Even the most enthusiastic Moon-watcher sometimes feels frustrated that we only ever see one side of our Moon, dubbed the near side. Because the Moon is tidally locked with Earth it spins around on its axis at the same speed at which it orbits our planet, so we always see the same side. Our side is magnificent, no doubt about that, but every lunar observer has looked up at the Moon at some point and wished that just once they could see its farthest limb with their own eyes and through their telescope.

The side of the Moon which is always hidden from our view is often referred to as the dark side, but it is not dark, at least not all the time, as many people think. When you actually think about it, when the Moon is new for us it must be full from the other side, illuminated by the Sun, so why is it called the dark side so often, when it gets just as much sunlight as our side? Some people genuinely think it is always in darkness, as they don't see it lit up. Other people think that the dark side refers to the way it is dark in terms of its visibility to us.

Some people have seen the far side of the Moon in person: the Apollo astronauts looked down on it from

their cramped capsules with wonder as it slid beneath them. Moon-orbiting satellites have photographed the far side of the Moon in as much detail as the near side, too. But looking at photos isn't the same thing as actually seeing something. If you could magically reach up into the sky, grab the Moon and twist it round like a light bulb, what would you see?

The first thing you would notice is that there are none of the big, dark areas - the mare, or seas - that are painted on our side of the Moon. In fact, while 13 per cent of the near side is covered with the dark lava plains of mare, only one per cent of the far side is. Looking at the far side from your garden you would only really be able to see one small sea - Mare Moscoviense - up near the top left of the Moon, looking like a mini version of Mare Crisium.

You would be able to see lots of craters though, some of them huge. In fact, almost the whole of the south polar region of the Moon is one huge crater, the South Pole-Aitken Basin, an impact feature

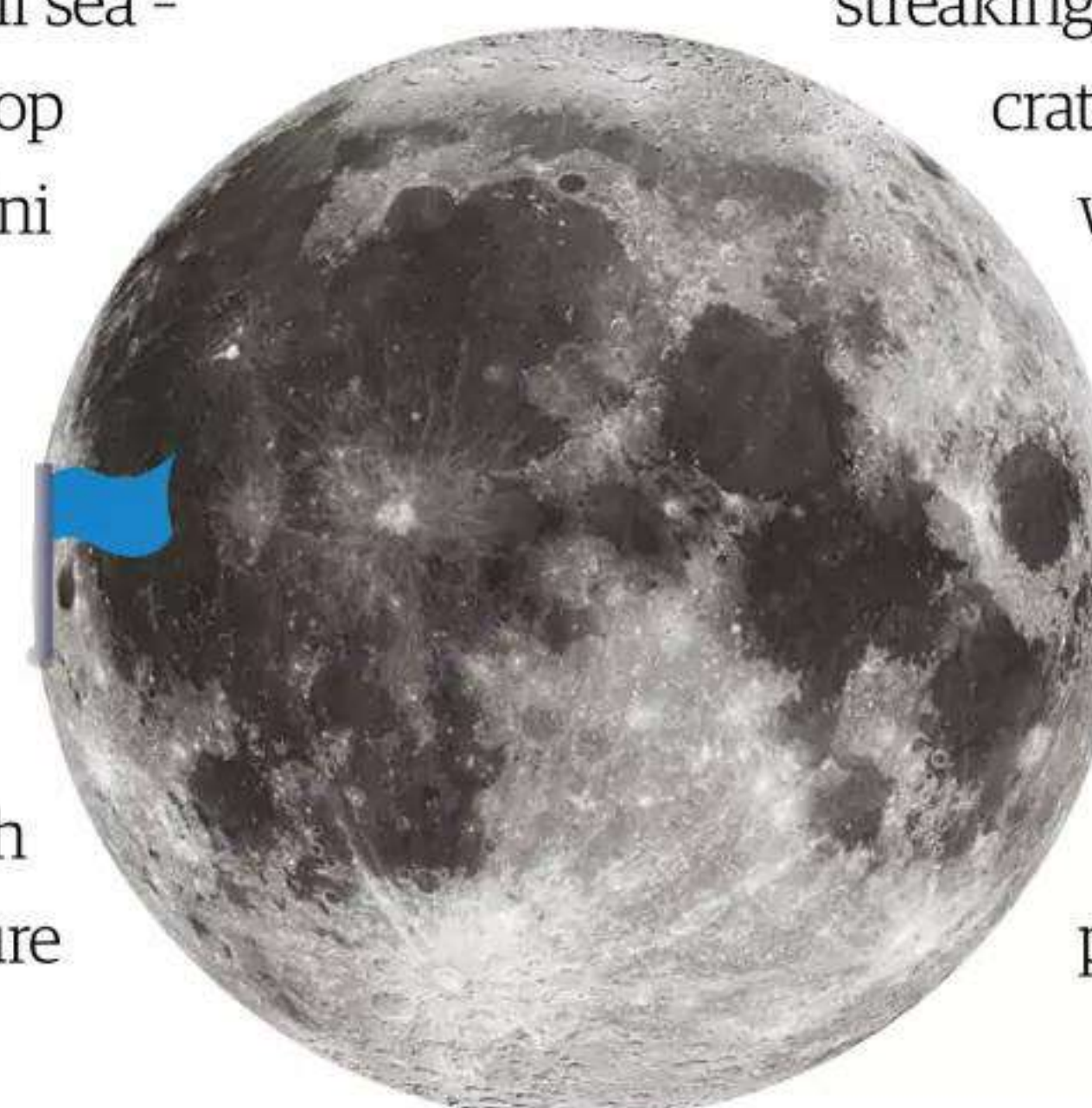
2,500 kilometres (1,553 miles) across and 13 kilometres (eight miles) deep which was blasted out of the Moon by an enormous impact billions of years ago.

And while it's not technically on the side of the Moon directly opposite ours, if you turned the Moon further around you would be able to see Mare Orientale, the Eastern Sea. Made up of three rings of jagged mountains, this spectacular impact feature looks like an archery bullseye. It was blasted out of the Moon more than 3.8 billion years ago by an asteroid perhaps 60 kilometres (37 miles) across.

Before you feel too cheated, consider this: if you enjoy looking at those craters with bright rays of debris streaking away from them - like the celebrity

craters Tycho, Copernicus and Kepler - you wouldn't see them if we swapped sides.

At full Moon you would see some impressive rays streaking away from the crater Jackson, over to the right of Mare Moscoviense, but with no dark seas for meteoroids to hit and spray with debris, the far side is very poor for rays compared to our side.



Naked eye & binocular targets

These circumpolar targets can be spotted lurking around Perseus and Andromeda

4 Double Cluster (NGC 869 and NGC 884)

The Double Cluster is made up of two open star clusters, each containing between 300 and 400 stars, sitting side by side at a distance of approximately 7,000 light years away from Earth. They can be located by following the imaginary line from Navi through Ruchbah, both of Cassiopeia, likewise to locating Mirfak.

5 Caldwell 28 (NGC 752)

Caldwell 28 is another open star cluster located just next door in the constellation of Andromeda. It is on the outskirts of Andromeda and is only five degrees south of the star Almach (Gamma Andromedae). This cluster contains roughly 50 stars spread out over a 1.25-degree patch of the sky.

Cassiopeia

Andromeda

Triangulum

Perseus

1 Mirfak (Alpha Persei)

Perseus' brightest star, Mirfak, is just one star in an open star cluster referred to as the Alpha Persei Cluster. This star can be easily located by tracing the imaginary line starting at the star Navi (Gamma Cassiopeiae) of Cassiopeia through Ruchbah (Delta Cassiopeiae) and the Double Cluster until Mirfak comes into vision.

3 The Spiral Cluster (Messier 34)

Discovered by Italian astronomer Giovanni Batista Hodierna before 1654, the Spiral Cluster lies just five degrees away from Algol, making it easy to find. It is a young open star cluster, thought to be no older than 250 million years old, and can even be resolved using 10x50 binoculars.

2 Algol (Beta Persei)

Algol, also known as the 'Devil Star', experiences a regular brightness variation, seeing it dip from a magnitude of +2.1 to +3.4 every two days, 20 hours and 49 minutes. This is because Algol is a three-star system, and the dimmer Beta Persei B eclipses brighter Beta Persei A with clockwork precision.



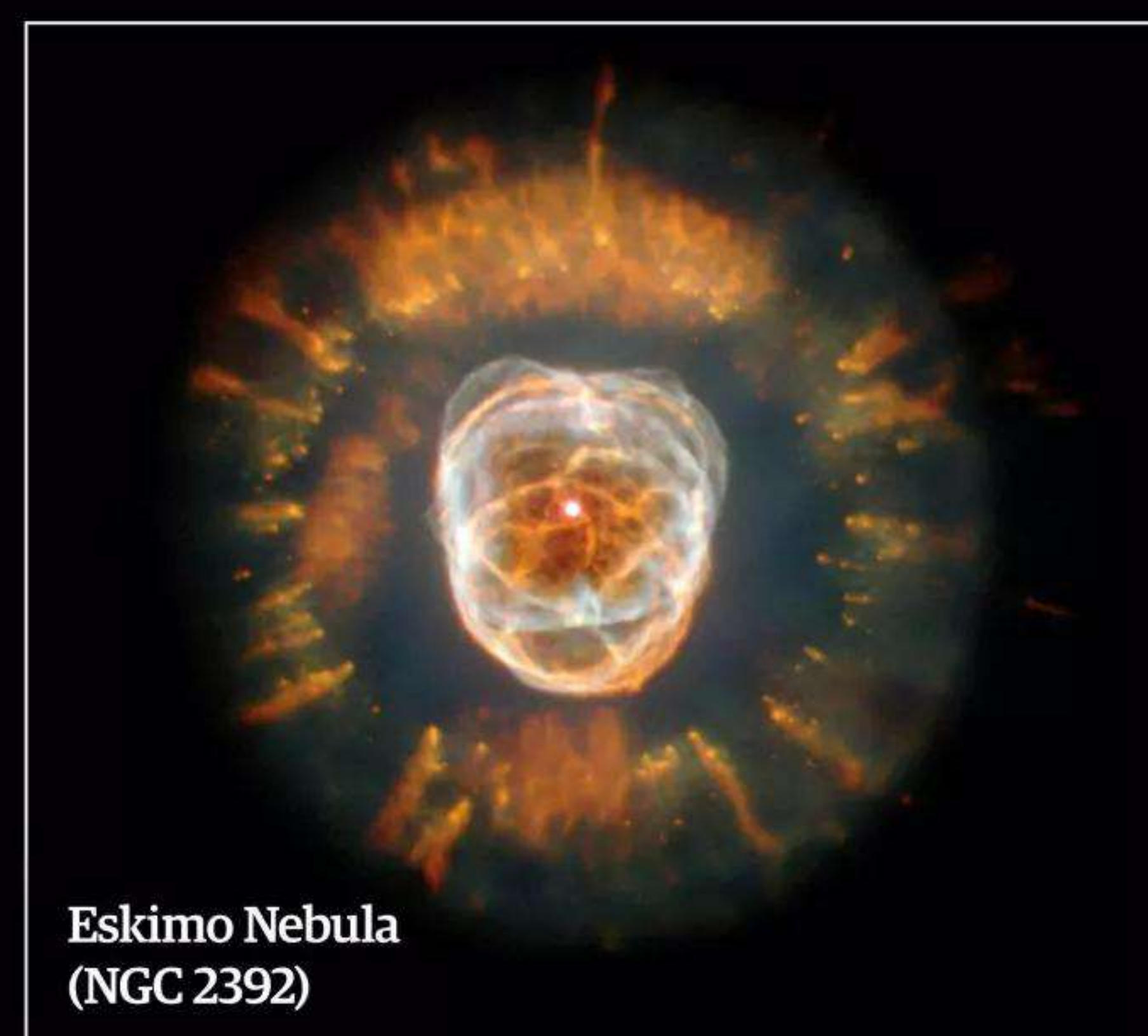
Deep sky challenge

The twins' secret treasures

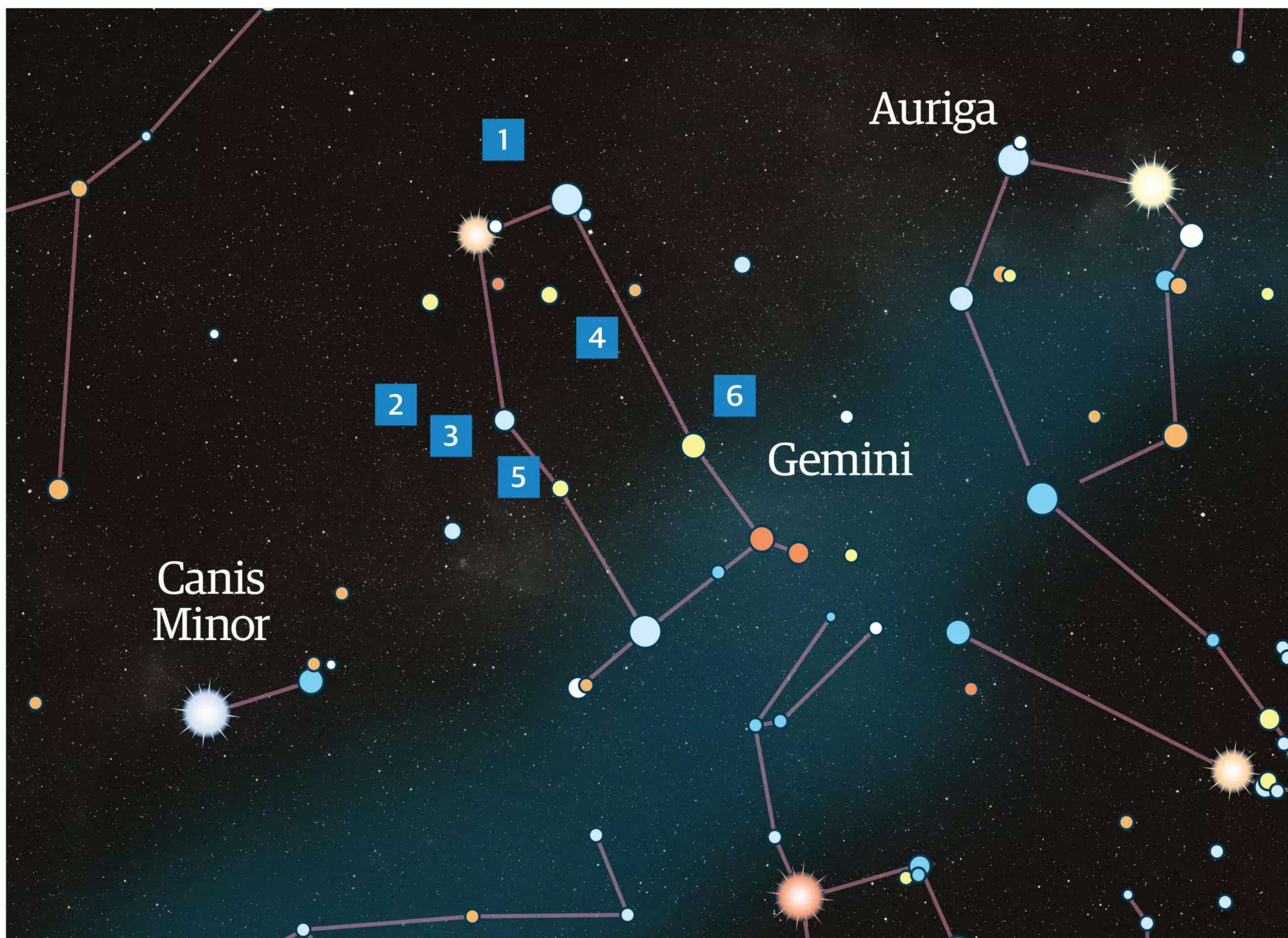
Track down some lesser known wonders on the next clear and frosty night

As you set up your telescope on freezing cold November nights, it's always tempting to look at the same things you always do: the misty, swirling veils of the Orion Nebula, the Pleiades cluster with its stars sparkling like jewels and the Crab Nebula's ghostly haze all call out to you through your favourite eyepiece. But there is much more to the winter sky than those 'celebrity' objects, and if you swing your ice-cold telescope tube towards the constellation of Gemini, put in a high-power eyepiece and go deep - very deep - you can see some lesser-known objects that deserve your attention just as much as their more famous neighbours.

Gemini is dominated by the open star cluster Messier 35, one of winter's showcase objects, and it's a beautiful sight in anything from a humble pair of binoculars to a huge Dobsonian. Scattered around it are much fainter, much more distant objects that are real treats once tracked down. The Eskimo Nebula - sometimes known as the Clownface Nebula - is a lovely, intriguing planetary nebula that shows fascinating detail and structure through a large telescope, while the Twinkling Comet Cluster (NGC 2420) and spiral galaxy NGC 2339, which rests more than 250 million light years away, are also worthwhile targets to seek out with your telescope.



Eskimo Nebula
(NGC 2392)



1 NGC 2435

This spiral galaxy, sitting almost edge-on to us, is 200 million light years away. Measuring just 15 arc minutes across and shining at a very faint 13th magnitude, it is a challenge in even a large telescope.

3 The Eskimo Nebula (NGC 2392)

In a large telescope's high-power eyepiece this ninth-magnitude planetary nebula really does look like a face surrounded by a hood - Eskimo or clown...? You decide.

5 NGC 2339

You'll need a large telescope, dark skies and high magnification to see this 250 million light year distant galaxy. Under perfect conditions you will see hints of its tightly wound spiral arms.

2 The Twinkling Comet Cluster (NGC 2420)

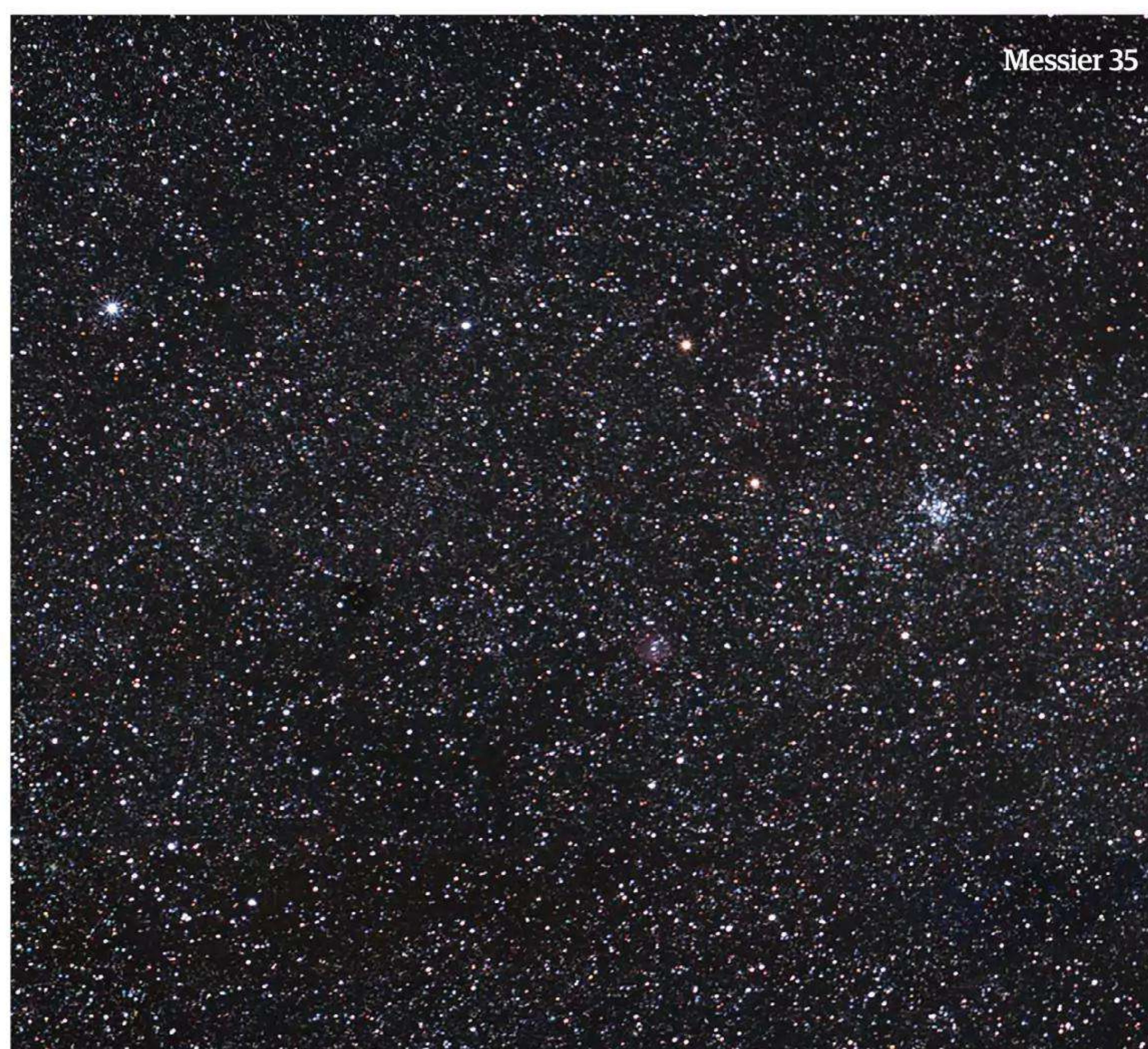
This eighth-magnitude cluster looks nothing like a comet; it is more of a loose spray of stars in the centre of a keystone of four brighter stars.

4 NGC 2331

Sitting some 4,200 light years from Earth, this sparse open cluster shines at eighth magnitude. A telescope's medium-power eyepiece will show it as a loose, irregular clump of around 30 stars.

6 NGC 2266

Dominated by a chain of bright stars that cuts across its centre like a mini Orion's Belt, this roughly triangular magnitude +9.5 cluster is a real treat in both medium and large telescopes.





The Northern Hemisphere

Astronomers will need to wrap up warm to make the most of the winter sky

With Bonfire Night beginning our observing period this month, astronomers can officially make the most of the darker evenings. Having longer hours of darkness doesn't merely give sky-watchers more time to become reacquainted with old favourites - it also offers the chance to seek out previously unexplored targets.

If you're a fan of splitting double stars with a telescope, head over to the constellation of Aries (the Ram), which can be found surrounded by Taurus (the Bull), Pisces (the Fishes) and Cetus (the Whale). In particular, binary star systems Lambda Arietis, Epsilon Arietis and Mesarthim are splendid targets to resolve for astronomers with medium to large instruments.

Using the sky chart

This chart is for use at 22:00 (GMT) mid-month and is set for 52° latitude.

- 01 Hold the chart above your head with the bottom of the page in front of you.
- 02 Face south and notice that north on the chart is behind you.
- 03 The constellations on the chart should now match what you see in the sky.



Magnitudes

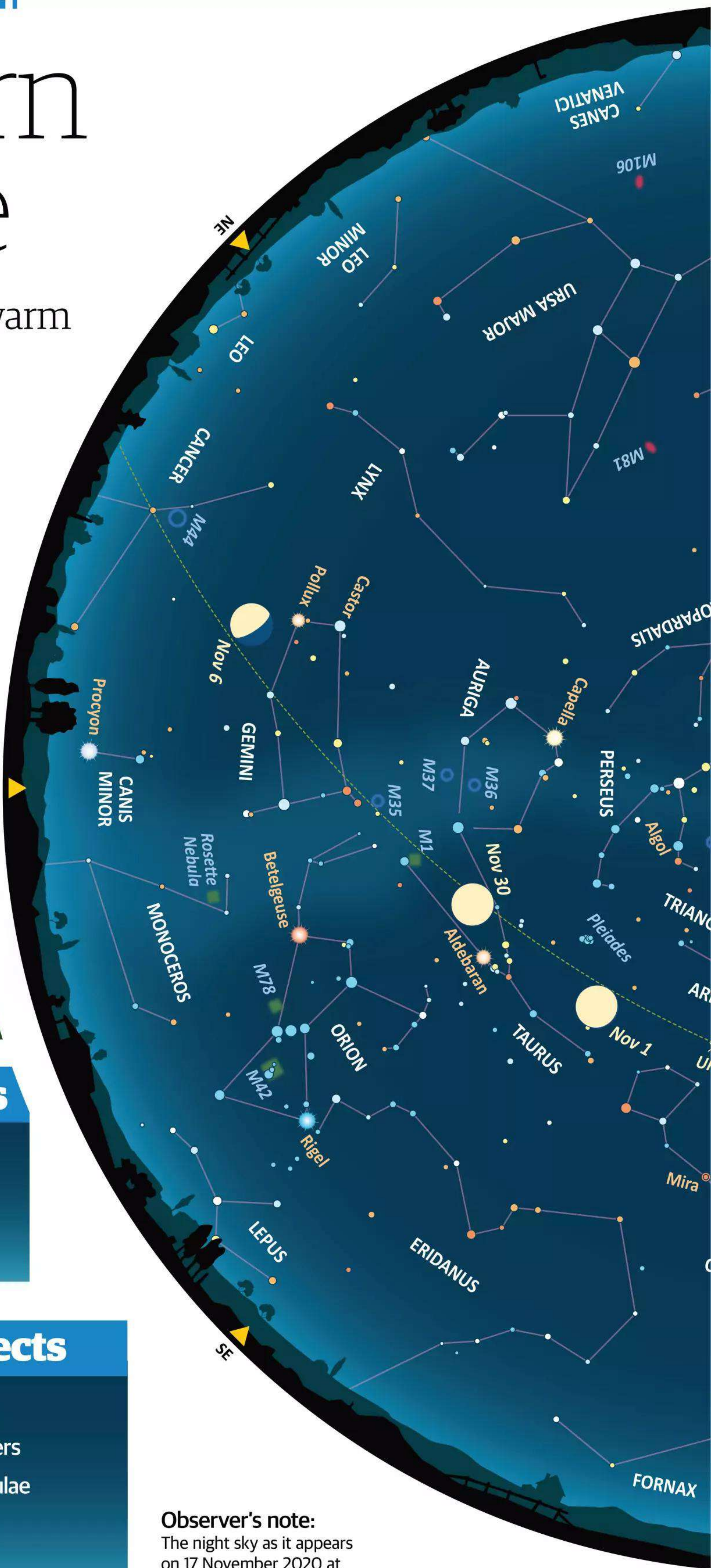
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

- | | |
|-------|-----|
| • O-B | • G |
| • A | • K |
| • F | • M |

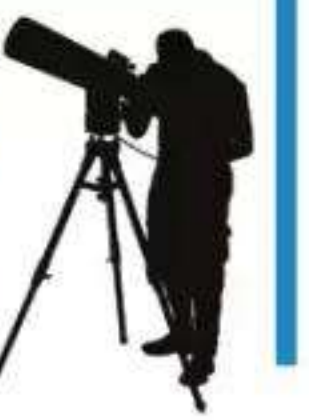
Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



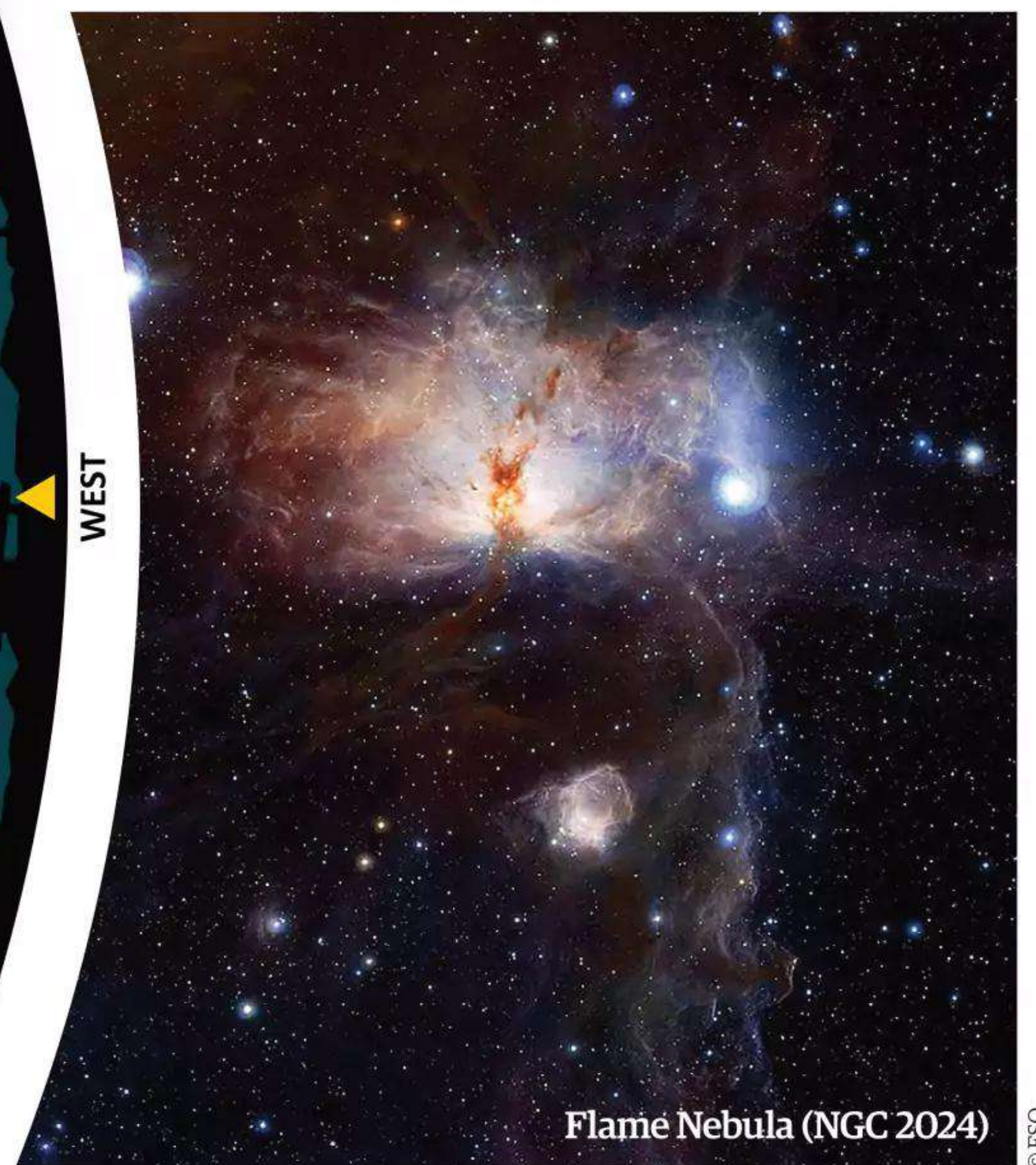
Observer's note:

The night sky as it appears on 17 November 2020 at approximately 22:00 (GMT)



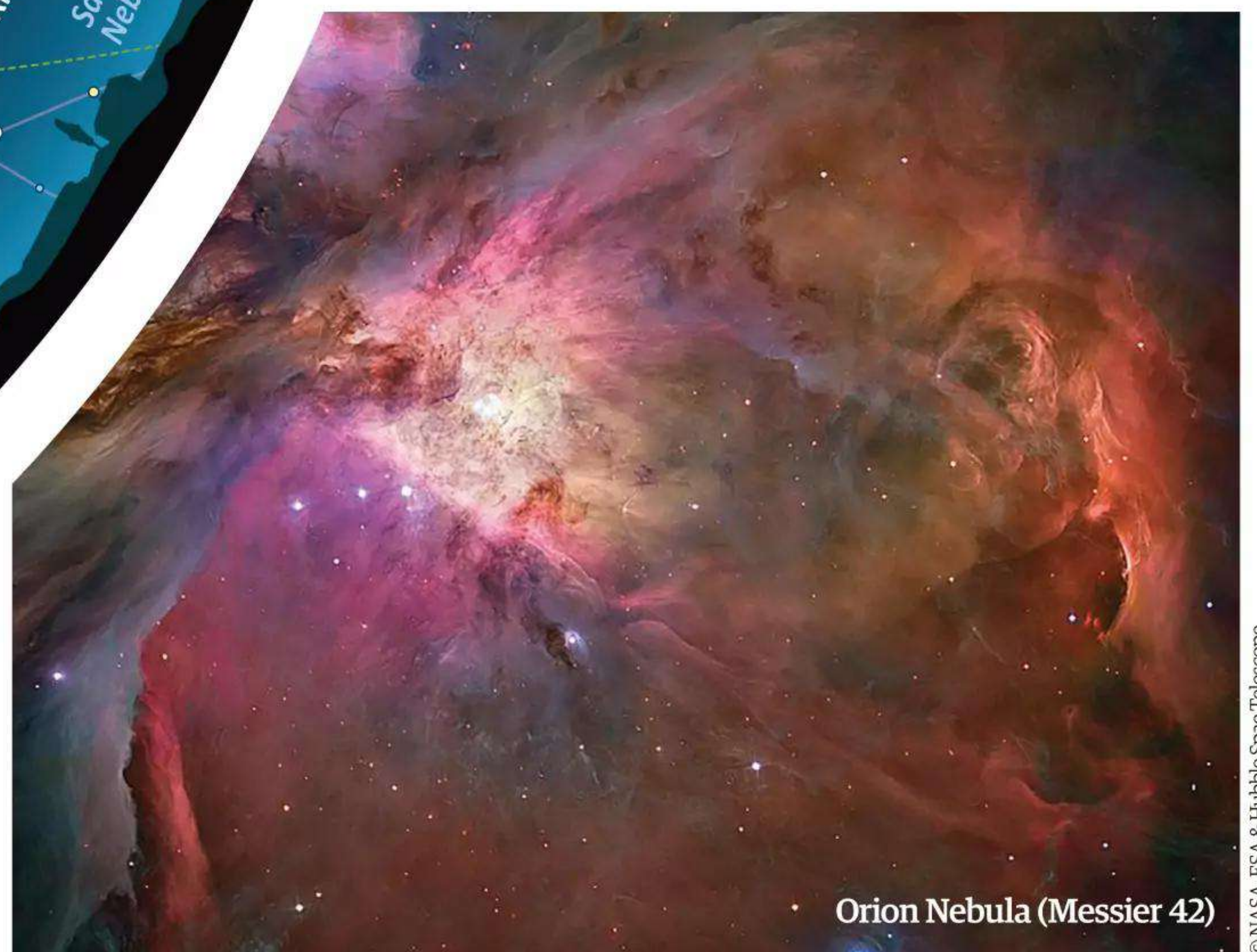
Rosette Nebula (Caldwell 49)

Source: Wikipedia Commons © Azhikerdute



Flame Nebula (NGC 2024)

© ESO



Orion Nebula (Messier 42)

© NASA, ESA & Hubble Space Telescope

Celestron Cosmos 90GT WiFi telescope

A refractor with a next-generation twist, the Cosmos 90GT is ideal for beginners looking to observe a wide variety of targets

Telescope advice

Cost: £428 (approx. \$543)

From: Amazon

Type: Refractor

Aperture: 3.54"

Focal length: 36"

Best for...

-  Beginners
-  Medium budgets
-  Planetary viewing
-  Lunar viewing
-  Bright deep-sky objects

We're all familiar with Neil deGrasse Tyson's *Cosmos: A Spacetime Odyssey*, which is a reboot of Carl Sagan's *Cosmos: A Personal Voyage*, originally broadcast in the 1980s. Now there's a night-sky instrument to match the space series, as telescope manufacturer Celestron has produced a refractor in association with the TV series that hit our screens back in 2014.

On unboxing, we didn't need to take much time putting the instrument together, and the final set-up boasted a fairly built, high-quality telescope. On seeing the single fork arm alt-azimuth mount and the battery pack, able to hold eight AA batteries, we immediately drew comparisons with the Celestron NexStar 6SE, which we've reviewed previously. However, despite the Cosmos 90GT's similarities with the NexStar 6SE, it doesn't come with a handset to assist the beginner with finding their way around the night sky. The main idea is that users will need to use an internet-enabled smartphone or tablet to locate and identify any targets of interest. Some may be a tad put off at this point, but let us assure you that connecting the telescope's built-in SkyQ Link WiFi network to a smartphone or tablet and downloading the free Cosmos Navigator app is extremely straightforward.

Getting down to actually operating the telescope, using our device was even more intuitive as we used the on-screen control buttons to slew the telescope. Using the app on an iPhone, we located yellow giant star Dubhe in the constellation Ursa Major and tapped it gently to select the GoTo

option. The Cosmos 90GT responded quickly and moved to the target ready for us to observe - a highly impressive function of this refractor and something that beginners to observing will be grateful for.

The connection between our smartphone and the SkyQ Link WiFi network was very steady during our test of the instrument. On a couple of occasions using the refractor, we disconnected from the WiFi manually to see if the telescope is capable of picking up from where it left off. We weren't disappointed - the Cosmos 90GT connected quickly and didn't need realignment, meaning that we could go back to viewing the last target we were observing. However, when the telescope's power goes off you will have to go through the realignment process again - nothing major, especially given the time it takes to set the refractor up ready for observations. The telescope didn't drain batteries quickly either, and were still good to go even after our three-hour review.

Celestron has also ensured that this next-generation telescope is accessible for those who do not have a tablet or smartphone. The Cosmos 90GT can be operated by a NexStar handset (sold separately) by plugging it into the auxiliary port on the single-arm mount. We should point out that the telescope is pretty much useless without any of these devices to control it. In our opinion though, we think that owners of this telescope should take full advantage of its WiFi capabilities.

The 90GT comes very well equipped, ensuring that the beginner has a good package to get them started in a very rewarding hobby. Two high-quality 1.25" Plössl's - a 25mm and 10mm, providing magnifications of 36x and 91x respectively - are thrown in and work with the telescope's optical system to provide very good views of a selection of deep-sky and planetary objects, as well as the craters and lunar mare of the Moon. Fully coated optics ensure very good light transmission for clear, sharp views, and the light-gathering power is 165-times greater than the human eye.

During our observations, we made the most of Venus and Jupiter, which were visible in a southerly to westerly sky. Venus dazzled as a bright

Right: With the supplied eyepieces the Cosmos 90GT provided sharp sights across a reasonable proportion - around 80 per cent - of the field of view

Left: A StarPointer red-dot finder, which features a switch to vary brightness, is useful for the alignment process





"OWNERS OF THIS TELESCOPE
SHOULD TAKE FULL ADVANTAGE
OF ITS WIFI CAPABILITIES"



featureless point of light, devoid of any colour-fringing, while pleasing views of Jupiter and four of its largest moons - Ganymede, Io, Europa and Callisto - were had. Turning to the Moon, some craters and lunar mare were a stunning sight.

Below: Two good-quality 1.25" Plössl - a 25mm and 10mm - provide magnifications of 36x and 91x respectively

However, since the entirety of the face of our lunar companion was illuminated, thus washing out a great deal of surface detail, we targeted the more obvious features of the Moon such as craters Tycho and Copernicus, as well as the lunar seas Oceanus Procellarum and Mare Imbrium. Views of the Moon through this refractor are stunning, and we have no doubt that this telescope will deliver in providing exquisite detail of the lunar surface along the terminator during the Moon's phases.

We quickly identified the Beehive Cluster (M44) in the constellation of Cancer as a smudge in the night sky to the naked eye, close to Jupiter and the brightest star in the constellation Leo, Regulus - also known as Alpha Leonis. The Cosmos 90GT transformed the cluster into a stunning swarm of thousands of high-resolution blue-white stars. Turning our attention to Regulus, we were able to easily resolve it into a double star: Regulus A shone a brilliant blue-white compared to its companion Sun-like star, Regulus B.

A very good, easily transportable telescope for beginners, the Cosmos 90GT is an affordable instrument for astronomers wishing to observe a variety of night-sky targets with minimum fuss.

Wilhelm Röntgen

The discoverer of X-rays, his findings won him the first Nobel Prize in Physics

The Nobel Prize in Physics is littered with big names of scientists who have made outstanding contributions to the field of astronomy and astrophysics, including Albert Einstein, Marie Curie, Enrico Fermi and so many more. However, someone had to win the first. Wilhelm Röntgen became the first laureate of this prestigious physics prize in 1901 for his discovery of X-rays, which are also known as Röntgen rays.

Born on 27 March 1845 in Lennep in the Lower Rhine Province of Germany, Röntgen and his family moved to Apeldoorn in the Netherlands when he was three years old. In 1865 Röntgen entered the University of Utrecht to study physics, but he did not have the requirements to enrol as a regular student. Instead he went to the Federal Polytechnic Institute - now known as ETH Zurich - in Switzerland and passed the entrance exams, where he then studied mechanical engineering. He gained his PhD from the University of Zurich in 1869 and continued to work closely with Professor August Kundt, whom he followed to the newly founded, then-German Kaiser-Wilhelms-Universität in Strasbourg, France, three years later.

Between 1870 and 1900, Röntgen took several positions - and also rejected several others - from institutes across Europe, most of which were in Germany. In 1900 he accepted his last position as the chair of physics at the University of Munich in Germany. In fact, the Bavarian government had sent a special request to have Röntgen at their institution.

Röntgen's most famous research started in 1895. At this time he was investigating how electrical rays travel from an induction coil and through a partially evacuated glass tube. He realised that if you turn off all the lights so there is no interference, the path of the electrical rays in the tube becomes fluorescent when spaced roughly two metres (6.5 feet) apart. After more investigation, he soon realised that objects could become transparent when present within these rays. His first X-ray picture showed his wife's hand and the silhouettes of her finger bones and wedding ring. These properties were like nothing



Roentgenium, a radioactive element, is named after Röntgen

ever seen before. Röntgen henceforth referred to these as X-rays, and in 1901 he was accredited with the first Nobel Prize in Physics win "in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him." His generosity deserved another prize on top of that, as he donated his Nobel Prize money to the University of Würzburg, Germany, and refused to take out any patents on X-rays, making the technology available to the world.

The implications of X-rays have been groundbreaking, not only in the field of medicine with the introduction of X-ray machines, but also in astronomy. NASA's Chandra X-ray Observatory has been an excellent pioneer of this research since it was launched on 23 July 1999, tasked with studying the 'X-ray universe'. The observatory is attempting to reveal the hottest and most energetic regions of the universe, which are not observable in the visible light spectrum. It has helped inform astronomers about the workings of the material within galaxy clusters, exploding stars and gas swirling around the event horizon of a black hole.

"His first X-ray picture showed his wife's hand and the silhouettes of her finger bones"

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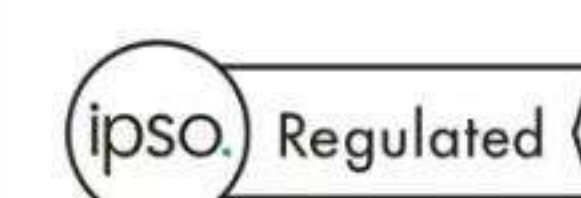


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